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REPORT TO

MINNESOTA POLLUTION CONTROL AGENCY

SOIL AND GROUND WATER INVESTIGATION

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COAL TAR DISTILLATION & WOOD PRESERVING SITE
ST. LOUIS PARK, MINNESOTA

BARR ENGINEERING CO.

JUNE 1977

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MINNESOTA POLLUTION CONTROL AGENCY

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FORMER COAL-TAR DISTILLATION AND WOOD PRESERVING FACILITY

ST. LOUIS PARK, MINNESOTA

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I hereby certify that the engineering aspects of this report were prepared by me or under my direct supervision and that I am a duly Registered Professional Engineer under the laws of the State of Minnesota.

Allan Gebhard

Allan Gebhard

Date: July 25, 1977 Reg. No. 9421

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SOIL AND GROUND WATER INVESTIGATION
FORMER COAL TAR DISTILLATION AND WOOD PRESERVING FACILITY
ST. LOUIS PARK, MINNESOTA

SUMMARY

The purpose of the study summarized in this report is to assess the impacts of the fomer coal-tar distillation and wood preserving facility on the soil and ground water systems in the surrounding area. Specifically, the objectives of the study are to:

a. measure the extent of coal-tar wastes in the soil,

b. measure the effect of these wastes on surficial and bedrock ground water quality,

c. define the interactions between the surficial ground water systems and the underlying bedrock aquifers.

d. predict future impacts of the waste deposits on ground water quality and

e. recommend corrective actions and further studies necessary to solve any identified problems.

The data collection activites for this study were divided into two phases so the early data could be reviewed and the work plan adjusted as necessary to meet the above objectives. The data collected in the first phase of the study were summarized and interpreted in a report to the Minnesota Pollution Control Agency titled "Phase I Report, Soil and Ground Water Investigation, Coal-Tar Distillation and Wood Preserving Site, St. Louis Park, Minnesota", dated May 1976.

To meet the objectives, a number of data collection activities were carried out.

Seventeen soil borings were placed to collect soil samples for chemical analysis and to define the stratigraphy of the glacial soils in the study area. Borings were placed on the northern half of the site, in areas on the southern half of the site suspected of being saturated with coal-tar derivatives during facility operation and in areas south of the site in drainageways and waste catchment areas. Soil samples were collected at 5-foot intervals and where coal-tar wastes were visible, samples were collected at 2-1/2 foot intervals.

Glacial soils in the area are complex and are characterized by fine sands to coarse gravels separated by glacial till strata ranging from fine silty sands to a sandy clay. The glacial soils in the area were found to be characterized by four distinct strata. These are:

a. the upper drift which consists of organic soils running north-south through the study areas and outwash deposits on either side of the organic soils,

b. the middle drift aquifer which consists of glacial outwash and ice contact deposits,

c. a till stratum separating the upper drift from the middle drift aquifer and

d. the lower drift which consists of a complex mixture of sands and till.

The chemical analyses of soil samples included measuring phenolic and benzene extractable materials as a gross indicator of the relative amount of coal-tar derived wastes present in the soils. The results of these analyses were used to draw contours of equal benzene extractable concentrations and equal phenolic concentrations on various geologic sections through the study area.

In addition to the measurement of phenolic and benzene extractable concentrations, fifteen soil samples were analyzed using thin-layer chromatography to determine the presence or absence of polynuclear organic materials in the samples. Gas chromatography was then carried out on six of the samples to define the concentrations of the various polynuclear organics that were present. The objective of this analysis was to define the extent to which the polynuclear organic materials are moving from the coal-tar wastes identified in the various soil borings.

A total of sixteen ground water monitoring wells and three small diameter ground water piezometers were installed during the study. The monitoring wells were located in the St. Peter sandstone, the Platteville limestone, at the lower drift/bedrock contact and in the middle drift aquifer. Monitoring wells were used to measure piezometric levels and to collect representative samples of the ground water in the various strata. Piezometric levels along with permeabilities obtained from the literature, from pumping tests or from soil samples were used to define the direction and rate of ground water movement in the glacial drift and in the underlying bedrock aquifers during summer and winter conditions. Ground water samples from the wells and from industrial and municipal wells in the general study area were analyzed for phenolics, polynuclear aromatic hydrocarbons, oil and grease, biochemical oxygen demand, chemical oxygen demand, total dissolved solids, arsenic, copper, cadmium and other selected parameters likely associated with wastes from coal-tar distillation and wood preserving facilities.

Based on the analyses carried out in this study, the following conclusions are made:

1. Analytically detectable quantities of coal-tar derivatives were present in approximately 90 percent of the soil samples collected and analyzed during this study. Coal-tar derivatives are present in much greater concentrations throughout the soil column on the southern portion of the coal-tar distillation and wood-preserving site and south of the site than on the northern one-half of the site. For example, benzene extractable concentrations greater than 1,000 mg/kg are present at a depth of 50 feet south of the site, whereas they are typically present at concentrations between 100 mg/kg and 200 mg/kg below the

surface soils on the northern portion of the site. Chrysene, benz(a)pyrene, benz(c)phenanthrene and a number of other unidentified polynuclear aromatic hydrocarbons are present in the visible coal-tar wastes found near the surface throughout the study area and at depth south of the site. No attempt was made in this study to define the public health risks associated with these materials in the soil.

2. Ground water in the glacial drift south and southeast of the site is moving laterally through the outwash material and vertically into the Platteville limestone. Vertical flow to the Platteville in the area southeast of the site is equal to or greater than lateral flow through the outwash. Ground water movement through the Platteville is lateral, most likely toward the buried bedrock valley southeast of the site.

3. Ground water in the glacial drift south and southeast of the coal-tar distillation and wood-preserving site is contaminated with coal-tar derivatives. From its point of deposit by surface flows, the movement of the waste has been lateral with ground water flow and vertical due to its higher specific gravity and due to the vertical ground water movement. The wastes contain measurable phenolics and polynuclear aromatic hydrocarbons such as pyrine. Polynuclear aromatic hydrocarbon concentrations of 3,400 mg/l and phenolic concentrations of 50 mg/l have been detected at a depth of 50' below the ground surface in the area between Lake Street and Highway 7. These wastes have traveled at least 1,000' to the southeast and to the glacial drift/bedrock contact where polynuclear aromatic hydrocarbon concentrations of 1.7 mg/l and phenolic concentrations of .3 mg/l have been measured. Thus, it can be concluded that phenolics and polynuclear aromatic hydrocarbons are contained in ground water reaching

the Platteville limestone over at least a portion of the area southeast of the site. No attempt has been made in this study to define the public health risks associated with these materials in the ground water.

4. Phenolic concentration contours in the glacial drift south and southeast of the site are likely moving southeastward at rates between 30 and 150 feet per year. Ground water quality in the glacial drift aquifer is not at a steady-state condition and the concentration of coal-tar derivatives will continue to increase away from the area of concentrated coal-tar waste. Reasonable estimates of flow through the Platteville limestone indicate that water in the Platteville takes on the order of 20 to 50 years to reach the buried bedrock valley from the area southeast of the site although flow times could be much less. The quality of water moving through the Platteville is also not at a steady-state condition and the concentrations of coal-tar derivatives will likely continue to increase.

5. The buried bedrock valley southeast of the site is a recharge area to the St. Peter sandstone. Ground water reaching the buried valley either through the glacial drift or the Platteville can enter the St. Peter sandstone. From the buried valley, movement will likely be eastward out of the study area. The potential effect of this movement was not determined.

6. A number of wells in the area are uncased through two or more bedrock aquifers and thus provide potential pathways for ground water to move between the upper more contaminated aquifers such as the glacial drift and Platteville and the lower aquifers.

7. Data collected for this study supports earlier data that indicate very low, but detectable concentrations of phenolic compounds in bedrock wells beneath the site and at a municipal well field located north of the site. The very low concentrations of phenolics in the St. Peter sandstone measured south and southeast of the site can be attributed to leakage through the Glenwood or to leakage through uncased wells. The trace phenolic concentrations measured in the Mt. Simon-Hinckley wells on the site and at the City's well field are attributed to movement of coal-tar derivatives from a Mt. Simon-Hinckley well on the site to the municipal well field. The available information, however, is not sufficient to explain the reason for the measured phenolic concentrations in the municipal St. Peter and Prairie du Chien-Jordan wells at the municipal field north of the site or at other municipal well fields in the area. In the case of the St. Peter wells, the gradients are sufficient to transmit seepage from uncased wells to the municipal well field; however, the time since construction of the uncased wells is too short for these wells to be the source of phenolics in the municipal wells. In the case of the Prairie du Chien-Jordan wells, the computed gradients indicate that ground water cannot be transmitted from the site to the municipal well field north of the site.

8. Since the quality of the water in the glacial drift and Platteville is not at a steady-state condition, the quality of water in the St. Peter aquifer, which is influenced by seepage from the glacial drift/Platteville, is also not at steady-state. Due to its greater distance from the area of waste concentration in the glacial drift, the quality of the water in the St. Peter will change more gradually than the quality of water in the drift or Platteville. Since the quality in the Prairie du Chien-Jordan cannot be explained by the available data, no

comments can be made about future changes in the quality of water in this aquifer. The quality of the water in the City's Mt. Simon-Hinckley wells is likely controlled by recharge through uncased Mt. Simon-Hinckley wells. Since future ground water quality around these uncased wells should not change significantly, it can be concluded that quality of the Mt. Simon-Hinckley aquifer has, for practical purposes, reached a steady-state condition. Thus, very little change in the quality of this aquifer is anticipated due to the wastes discharged from the former coal-tar distillation and wood-preserving facility.

9. The coal-tar derivatives in the glacial drift ground water system represent a potential threat to the underlying ground water aquifers due to the uncased wells, due to flow to the buried bedrock valley, due to seepage through the Glenwood and due to the fact that existing industrial wells that acted as barriers to waste movement down-gradient of the contaminated ground water are being abandoned, thereby increasing the potential for the spread of the identified wastes.

TIMING OF CONTAMINAT[ION] WHAT IS LONG RANGE IMPACTS

10. The control of ground water movement in the glacial drift to prevent the spread of the coal-tar derivatives is technically feasible using a system of pump-out wells in the glacial drift to control ground water gradients. The system investigated in this study assumed one well placed in the area of severest contamination in the wetland area north of Lake Street and south of Highway 7 and two wells located to the east and southeast. The western gradient control well will remove the severest contamination that is likely the source of most coal-tar derivatives detected in this study. The eastern two wells will remove material that has escaped from this source and is traveling either through the drift or Platteville. Peak

phenolic concentrations in the discharge from the well system are predicted to be on the order of 1 to 3 milligrams per liter and peak polynuclear aromatic hydrocarbon concentrations are predicted to be on the order of 100 milligrams per liter. Concentrations of phenolics from the system are predicted to be less than .1 milligrams per liter after about 15 to 20 years of pumping while on the order of 50 to 100 years will likely be necessary to reduce phenolic concentrations below .01 milligrams per liter. The effect of desorption from soil particles could not be quantified, but will likely increase the pumping needed to reach these concentrations.

11. The sanitary sewer and the existing surface water treatment and disposal system were evaluated as disposal routes for the effluent from the gradient control wells. The most logical route for the effluent during times that high phenolic concentrations are produced will be the sanitary sewer. Sanitary sewer disposal is estimated to cost on the order of $10,000 to $15,000 per year. A service availability charge of approximately $100,000, however, could be assessed by the Metropolitan Waste Control Commission if the discharge is judged to be permanent. The second disposal route is the existing treatment facility that is in place to treat storm water runoff from the site prior to discharge to Minnehaha Creek. In concept, the existing treatment system could provide the required treatment. Bench scale and pilot scale studies will be needed to determine if modifications to the existing facility will be necessary to treat the effluent. Combinations of these two disposal routes are possible, such as disposal of effluent from the western gradient control well to the sanitary sewer system and disposal of effluent from the eastern wells to the existing surface water treatment facility.

12. The volumes of soil that must be excavated to remove various concentrations of phenolics and benzene extractable material in the soils were evaluated. On the order of 700,000 cubic yards of soil must be excavated to remove all soil with phenolic concentrations greater than 1 mg/kg. On the order of 400,000 cubic yards of soil must be excavated to remove soils with benzene extractable concentrations greater than 1,000 mg/kg. Excavation of contaminated soil is not an alternative to gradient control. Excavation of the most contaminated soils will, however, reduce the time required to control gradients in the area. The amount of time reduction, however, is not quantifiable.

CAN THIS ALTERNATIVE BE ? DISMISSED?

? Why not

Based on the analyses carried out for this study and on the preceding conclusions, the following recommendations are made:

1. All bedrock wells constructed so as to provide pathways for ground water to move between the drift/Platteville and St. Peter and between the St. Peter or Prairie du Chien-Jordan and Mt. Simon-Hinckley aquifers should be grouted and abandoned. Highest priority should be given to locating and abandoning wells in the area bounded by Texas Avenue on the west, Minnetonka Boulevard on the north, Highway 100 on the east and Minnehaha Creek and Excelsior Boulevard on the south. Wells in this area should be located and abandoned immediately. The investigations summarized in this report indicate that these wells present potential pathways for the movement of coal-tar derivatives to the lower aquifers and, in fact, represent the only reasonable means by which ground water in the Prairie du Chien-Jordan and in the Mt. Simon-Hinckley formation could be contaminated with waste from the site of the former coal-tar distillation and wood-preserving facility.

How does this occur?

2. Since the abandonment of uncased wells near the site will likely result in the movement of recharge from the buried valley to the St. Louis Park municipal well field to the north, St. Louis Park wells 1, 2 and 3 should also be abandoned.

3. The potential impact of the identified high concentrations of coal-tar derivatives in the glacial drift ground water are significant enough that mitigative measures are recommended to halt the movement of these wastes.

4. The control of ground water gradients in the glacial drift ground water system is technically feasible and the system presented in this report or a similar system should be implemented. It is recommended that design of the gradient control wells begin immediately. The first step in the design will be to place the additional wells and borings needed to define the exact location of gradient control wells. The next step will be to place one or more test wells to verify the aquifer characteristics needed to complete the design. The third step will be to complete the design and construct the wells.

HOW MUCH

5. Water pumped from the gradient control wells should be discharged to the sanitary sewer, at least initially. After the more highly contaminated ground water has been removed from the glacial drift or after treatability of the waste has been better defined, it may be possible to discharge the effluent from the wells to Minnehaha Creek after appropriate treatment.

6. Bench scale and pilot scale studies should be conducted to define the treatability of the ground water using either the existing surface water treatment facility or a new treatment concept.

7. The effectiveness of the gradient control system should be monitored both in terms of the ability of the wells to capture coal-tar derivatives through the glacial drift and Platteville limestone and, if the effluent is discharged to Minnehaha Creek, the ability of the treatment facility to meet effluent limitations prior to discharge.

8. Two additional wells should be placed in the St. Peter formation beneath the area of elevated coal-tar derivative at the drift/Platteville contact to monitor the quality of water in the St. Peter. If the average concentration of the phenolics, as measured by the MBTH Method, exceeds a concentration on the order of 20 micrograms per liter, significant change will have occurred and gradient control or some other appropriate mitigative measure should be required to control movement of the wastes in the St. Peter.

WHY THIS METHOD CAN'T BE REPRODUCE

9. Further information is needed regarding the effect of the trace phenolic concentrations measured in the municipal wells in St. Louis Park. It is recommended that studies be carried out to define the potential public health effect of these trace phenolics.

10. A better definition of hydrogeology is needed in the buried bedrock valley located near Highway 100 and Excelsior Boulevard. Specifically, soil borings and piezometers should be placed in the valley to define its extent and to estimate gradients and likely vertical flow rates. In addition, monitoring wells should be placed near the western edge of the valley to define the quality of water discharged to the valley from the site area through the glacial drift, Platteville and St. Peter units. A monitoring well should also be placed in the St. Peter north of the valley to monitor the quality of the water in the aquifer between the valley and the City well field to the north.

why in light of closing 1, 2, & 3

SECTION I

OBJECTIVES AND GENERAL APPROACH

SECTION I

STUDY OBJECTIVES AND GENERAL APPROACH

Between 1917 and 1972, a coal-tar distillation and wood-preserving facility was operated in the City of St. Louis Park north of Highway 7 and approximately 1 mile west of Highway 100. During operation, spills occurred and wastes were reportedly discharged to the environment. The purpose of the study summarized in this report is to assess the impacts of this facility on the soil and ground water systems in the area. Specifically, the objectives of the study are to:

a. measure the extent of coal-tar wastes in the soils,

b. measure the effect of these wastes on surficial and bedrock ground water quality,

c. define the interactions between the surficial ground water systems and the underlying bedrock aquifers,

d. predict future impacts of the waste deposits on ground water quality, and

e. recommend corrective actions and future studies necessary to solve any identified problems.

The data collection activities for the study were divided into two phases so that the early data could be reviewed and the work plan for the study adjusted, if necessary, to meet the above objectives. The early data collection activities were designed to define the vertical and horizontal extent of coal-tar wastes in the soils, define the quality of the glacial drift ground water system, and define the interactions between the glacial drift ground water system and the bedrock aquifers. The emphasis of the early data collection activities was placed on using general indicator parameters to broadly define the location and extent of coal-tar wastes in the soil and ground water and on carrying out a limited number of more detailed analyses to begin defining how the various compounds known to be in the wastes are migrating vertically and laterally through the glacial soils. Subsequent data collection activities were directed toward obtaining a better definition of ground water degradation south and southeast of the site of the former coal-tar and wood-preserving facility* and on obtaining a better definition of glacial drift and aquifer interactions. This information was then used to evaluate various corrective actions.controlling

The early data were summarized and interpreted in a report by Barr Engineering Co. to the Minnesota Pollution Control Agency titled "Phase I Report, Soil and Ground Water Investigation, Coal-Tar Distillation and Wood-Preserving Site, St. Louis Park, Minnesota," dated May, 1976. The general conclusions from the Phase I Report are summarized in Section II of this report.

After the early data were reviewed, the additional data collection activities necessary to attain the objectives of the study were defined and carried out. Concurrently with carrying out the additional data collection activities, the effects of the coal-tar wastes on surficial and bedrock ground water quality were predicted and techniques to mitigate the impacts of the wastes were evaluated.

Based on the early data, the emphasis of the additonal data collection activities was placed on:

a. further defining the condition of the surficial and bedrock ground water south and southeast of the site, and

b. assessing the interaction between the surficial and bedrock aquifers south and southeast of the site.

The emphasis of the portion of the study that assessed corrective measures was directed toward evaluating the technical feasibility of controlling

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*The area within the boundaries of the former coal-tar distillation and wood-preserving facility is referred to as the site.

ground water gradients. Since gradient control is relatively insensitive to the exact distribution of coal-tar wastes within the controlled area, further definition of the distribution of coal-tar waste in the glacial soils was assigned a lower priority than the definition of ground water conditions and the definition of aquifer interaction. If it was concluded that gradient control was not a technically feasible method of mitigating identified ground water problems, other forms of controlling the contamination, such as excavation, were to be evaluated. It was recognized, however, that further data collection efforts would likely then be needed to better define the exact distribution of coal-tar wastes in the soil.

The purpose of this report is to summarize the data collected during the study to summarize the assumptions and methods used to arrive at the conclusions and recommendations and to summarize the conclusions and recommendations themselves. The report is organized into seven sections. Section I is the discussion of study objectives and general approach. Section II summarizes the conclusions of the Phase I Report. Only data collected before publication of the Phase I Report that are especially pertinent to the final conclusions and recommendations of the study are included again in this final report. Section III of this report summarizes the data, detailed study methods and assumptions used to arrive at the conclusions and recommendations. Sections IV and V combine the data and study methods to define existing and predicted future ground water conditions. Section VI discusses the corrective measures that were evaluated to mitigate ground water problems identified in Sections IV and V. Section VII summarizes the conclusions of the study as well as corrective measures and further studies that are recommended.

S E C T I O N   I I

SYNOPSIS OF PHASE I REPORT

SECTION II

SYNOPSIS OF THE PHASE I REPORT

As discussed in Section I of this report, the data collection activities were divided into two phases so that the early data could be reviewed and the work plan adjusted, if necessary, to most effectively meet the study objectives. The early data collection activities were designed to begin defining:

a. the vertical and horizontal extent of coal-tar wastes in the soils overlying bedrock,

b. the general quality of ground water in the glacial drift, and

c. the interactions between the glacial drift and bedrock aquifers.

The emphasis of the early soil and ground water data collection activities was placed on using general indicator parameters to broadly define the location and extent of coal-tar wastes in the soil and ground water, and on carrying out a limited number of more detailed analyses to begin defining how the various compounds known to be in the wastes are migrating vertically and laterally.

Fourteen soil borings were placed during the early phase to collect soil samples for chemical analyses and to define the stratigraphy of the glacial soils in the area.* Borings were placed in the northern one-half of the site, in areas on the southern portion of the site suspected of being

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*For the soil investigation portion of the study, the term "study area" refers to the area within the boundaries of the former coal-tar and wood-preserving facility (referred to as the site), plus areas south of the site that received runoff from the site. For the ground water investigation portion of the study, the term "study area" refers to a larger area including the municipal wells located at the City of St. Louis Park's well field at 29th Street and Idaho Avenue.

saturated with coal-tar derivatives during facility operation, and in areas south of the site in drainageways and catchment areas. Soil samples were typically collected at 5-foot intervals throughout the soil column, except where visible coal-tar wastes were present when samples were ofter collected at 2-1/2 foot intervals. The requirements of the soil sampling program and the nature of the soils in the study area required that extreme care be taken to insure that representative soil samples were collected.

Soil samples collected from the fourteen borings were visually classified and this data were used to obtain a general picture of glacial stratigraphy overlying bedrock in the study area. Glacial soils in the area are characterized by glacial outwash and ice contact deposits ranging from fine sands to coarse gravels. These outwash and ice contact deposits are separated by glacial till strata ranging from fine silty sands to a sandy clay.

The chemical analyses of soil samples included measuring the phenolic material and benzene extractable material in all soil samples as a gross indicator of the relative amount of the coal-tar derived wastes present in the samples. Analytically detectable quantities of coal-tar wastes were present in approximately 90% of the soil samples collected from early soil borings placed in the area between the north boundary of the site and Lake Street. The phenolic and benzene extractable concentrations in the soil samples for each boring were used to draw contours of equal phenolic concentrations and equal benzene extractable concentrations on geologic sections through the study area. In general, the data indicated low, but still detectable, levels of phenolic and benzene extractable material in soil samples collected on the northern portion of the site. Highest concentrations of phenolic and benzene extractable concentrations were found south of the site between Walker Street and Lake Street with either low or undetectable levels of phenolics and benzene extractable material found in samples from the single boring placed south of Lake Street. The concentration contours indicated a generally increasing concentration of both phenolics

1000 gms/
1000 ml

and benzene extractable material with increasing depth in the glacial soils in a southerly and southeasterly direction from the site. Benzene extractable concentrations greater than 1,000 mg/kg are present at a depth of 50 feet south of the site. ppm

In addition to the analyses of phenolic and benzene extractable materials, eleven soil samples were analyzed using thin layer chromatography techniques to determine the presence or absence of polynuclear organic materials in the samples. Gas chromatography techniques were then carried out on five of the samples to define the concentrations of the various polynuclear organic materials that were present. The objective of the thin layer chromatography/gas chromatography analysis was to begin defining the extent to which the polynuclear organic materials are moving from the coal-tar wastes identified in the various soil borings. Since additional soil analyses were carried out after publication of the Phase I Report, the results of this entire portion of the investigation is discussed later in this report.

A total of nine ground water monitoring wells were installed during the early data collection activities. Ground water samples were collected from these monitoring wells, from three St. Louis Park City wells northeast of the site and from two industrial wells south and southeast of the site. The results of the analyses of these water samples have been combined with data from additional sampling to develop the conclusions regarding ground water quality presented in Section IV of this report.

The early studies of aquifer interaction revealed that soils in the study area exhibit a range of water-transmitting capabilities spanning seven orders of magnitude. Permeabilities of the outwash sands and gravels were found to be as high as 10 cm/sec (30,000 ft/day) while permeabilities of the clay till were found as low as 10^{-6} cm/sec (3×10^{-3} ft/day) in places. Two pumping tests carried out at the City well field located north of the site indicated that leakage through the confining bedrock aquitard separating the glacial soils from the upper sandstone aquifer (St. Peter) was not measurable and that the vertical permeability of the bedrock units between the St. Peter aquifer and the second sandstone aquifer (Jordan) was

DOES THIS NOT CONFIRM
A GOOD AQUITARD?

on the order of 10^{-6} cm/sec. Data from the two pumping tests were inconclusive, however, since the tests had to be of short duration to work around background fluctuations and City water nests, and since the characteristics of the wells used in the pumping tests were somewhat unknown.

The Phase I Report summarized and interpreted the data collected during the early stages of the study. Additional detail regarding this early data and data collection methods can be found in that report, in the various investigative memoranda that were prepared during the course of the data collection activities and in the reports furnished by the subcontracting laboratories included in Appendices A, B and C of the Phase I Report.

SECTION III

STUDY METHODS AND DATA

SECTION III

STUDY METHODS AND DATA

The purpose of this section of the report is to summarize the study methods, assumptions and data that form the basis for the conclusions and recommendations that are presented in the last three sections of this report. This section is divided into subsections that describe the soil, geologic, ground water movement and ground water quality investigations.

SOIL INVESTIGATIONS

A total of seventeen soil borings were placed in the study area during the course of this investigation. The locations of these seventeen soil borings are shown in Figure 1.* Soil Borings 1 through 14 were placed during the portion of the investigation summarized in the Phase I Report. Soil samples collected from these borings were analyzed for phenolic concentrations and benzene extractable concentrations. This information was used to construct contours of equal phenolic and benzene extractable concentrations at six vertical geologic sections through the study area. In addition, the grain-size distributions of a limited number of soil samples from these borings were measured and used to estimate permeabilities. The data from these soil borings are presented and discussed in the Phase I Report.

Soil Borings 15 through 17 were placed during the final phase of the study. These three borings were needed for the following reasons:

a. samples were needed from certain stratigraphic units for permeability analysis,

b. additional information was needed near the outer margins of the study area to extend the definition of glacial drift stratigraphy, and

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*All figures and tables are included after the text, but before the Appendices to this report.

c. information was needed regarding piezometric levels at the base of the glacial till.

The three soil borings placed in the latter stages of the project were placed in the vicinity of monitoring wells. These monitoring wells were typically in the higher glacial drift strata. Small diameter piezometers were installed in Soil Borings 15 through 17 to provide data on the piezometric levels at the base of the glacial drift. This, along with the water level in the monitoring well, provided information on the differences in piezometric level between the higher glacial drift aquifer and the base of the drift. These differences in piezometric level were then used as input data to estimate the vertical leakage through the aquitard separating the glacial drift aquifer and bedrock. The data obtained from these soil borings are discussed more fully in the subsections on geologic and ground water movement investigations.

During the portion of the study leading up to the Phase I Report, eleven soil samples were analyzed using thin layer chromatography techniques to qualitatively determine the presence of polynuclear organic materials in the soil samples. Gas chromatography techniques were then carried out on five of the samples to quantitatively define the concentration of six polynuclear organic materials. After publication of the Phase I Report, five additional samples were analyzed by thin layer chromatography techniques, and one of these samples was subsequently analyzed by gas chromatography. Two of these samples were collected from a soil boring placed in a typical urban area of St. Louis Park away from the study area to serve as a measure of background conditions. The objective of the thin layer chromatography/gas chromatography analysis was to define the extent to which the polynuclear organic materials are moving from the visible deposits of coal-tar wastes identified in the various soil borings. Since additional thin layer chromatography/gas chromatography data became available after publication of the Phase I Report, the entire data base on this subject will be discussed in this subsection.

A total of sixteen soil samples collected from Borings 1, 2, 5, 9 and 11 and from a "control" boring were analyzed by thin layer chromatography techniques during the course of this study. The following paragraphs briefly discuss the reasons for selecting soil samples from these borings.

a. Boring 1--Boring 1 was the northernmost boring located on the site in an area used for the storage of treated wood product. According to former employees of the coal-tar distillation and wood-preserving facility, the general area surrounding the location of Boring 1 was also used as a source of fill and as a dumping area for soil containing spilled product and waste material. Soil samples from the 10-foot depth and from the 55-foot depth were selected for analysis by thin layer chromatography. The sample from the 10-foot depth was immediately below the glacial drift ground water table in a silty, sandy clay material. The soil had a characteristic black color with a concentration of benzene extractable material of 2,200 mg/kg. Phenolics, however, were not detectable (<.2 mg/kg) in the sample, probably indicating that the soluble fraction had been leached from the sample. The soil sample from the 55-foot depth did not contain visible coal-tar material; however, a phenolic concentration of 1.0 mg/kg was measured.

b. Boring 2--Boring 2 was also located in the northern half of the site, approximately 400 feet southwest of Boring 1. Soil samples with benzene extractable concentrations exceeding 3,000 mg/kg were collected between the 8 and 11-foot depths in the upper portion of this boring above a lacustrine clay stratum. The sample from the 20-foot depth was selected for thin layer chromatography analysis. The sample was collected from a fine to medium sand stratum and exhibited a benzene extractable concentration of 125 mg/kg and a phenolic concentration of 0.6 mg/kg.

c. Boring 5--Boring 5 was located immediately northeast of the storm water storage pond recently constructed on the site. During operation of the coal-tar distillation and wood-preserving facility, an API Separator was located in this area. Coal-tar derivatives are known to exist above the saturated zone and coal-tar wastes could be seen seeping from the banks of the storm water storage pond during pond construction in late 1975. A soil sample from the 5-foot depth of Boring 5 with the characteristic black color and creosote-like odor was selected for analyses by thin layer chromatography techniques. In addition, soil samples collected immediately below the top of the saturated zone at a depth of 15 feet and at a depth of 30 feet were also selected for analysis by thin layer chromatography. The two deeper samples did not contain visible coal-tar wastes.

d. Boring 9--In Boring 9, surface peat and an organic silty clay stratum overlie a zone of sand visibly saturated with coal-tar waste. This sand stratum with visible coal-tar waste is immediately above a till stratum approximately 32 feet below the ground surface. A second stratum of sand visibly saturated with coal-tar waste was found immediately above a second till layer at a depth approximately 50 feet below the ground surface. One sample from the overlying peat, samples from the two sand strata overlying the two till layers and samples from the two till layers were selected for analysis using thin layer chromatography.

e. Boring 11--Boring 11 is approximately 300 feet east of Boring 9. Soil samples from Boring 11 did not indicate visible coal-tar wastes between the ground surface and bedrock, although a creosote-like odor was detected. The two till strata indicated in Boring 9, however, were also identified in Boring 11. Since ground water movement in the drift is easterly from the area of Boring 9 to Boring 11, soil samples were selected for analysis by thin layer chromatography techniques from the strata where coal-tar wastes were present in Boring 9.

f. Control Boring--Soil samples for thin layer chromatography analysis were collected from the 3-foot depth and from the 10-foot depth of a soil boring placed 100 feet west of Trunk Highway 100 near Cedar Lake Road in St. Louis Park. The purpose of this "control" boring was to collect information on the presence of polynuclear organic materials from a "typical" urban area. A boring adjacent to a major highway was selected since vehicle exhaust is a known source of polynuclear organic materials.

WHAT ABOUT AN AREA WHICH RECIEVES DIRECT DRAINAGE OF AN URBAN NATURE OR AN INDUSTRIAL OPERATION

The sixteen soil samples outlined in the preceding paragraphs were examined for polynuclear organic materials by Midwest Research Institute (MRI) at their Kansas City, Missouri laboratory. Soils were extracted with cyclohexane and the extracts were screened by thin layer chromatography on silica gel. Development with benzene-cyclohexane and visualization under long ultraviolet light indicated that polynuclear organic materials were present in all samples collected from the study area with the exception of the sample from the 55-foot depth of Boring 1. Highest concentrations were found in samples from the shallow strata of Borings 1 and 5 and from the two sand strata above the till layers in Boring 9. No bands indicative of polynuclear organic materials were detected in the thin layer chromatographic screening of the two samples from the control boring.

Thin layer chromatography plates for six soil extracts were scraped and reextracted for gas chromatographic examination. The polynuclear organics, 3-methyl cholanthrene and 3, 4, 6, 6-dibenzcarbazole were not identified in any extract; however, benz(c)phenanthrene, chrysene, benz(a)-pyrene and 7, 12- dimethylbenz(a)anthracene were measured in some soil samples. Several unassigned peaks in the gas chromatograph traces indicated notable quantities of other polynuclear organic material that could not be identified with standards available at MRI.

The results of the thin layer chromatography and gas chromatography analysis, as well as the phenolic and benzene extractable concentrations measured on the sixteen soil samples sent to MRI, are summarized in Table 1. The data indicate that polynuclear organic materials were present in fifteen of the sixteen soil samples collected from the study area with significantly higher concentrations present in the visibly contaminated soil samples collected at depth in Boring 9 and from near the surface in Borings 1 and 5. The soil samples that include the letters A and B from Boring 9 in Table 1 are samples where the sand-till interface was actually present in the soil sample. Samples SS-109B-1 and SS-109A-2 were collected from the sands overlying the till strata and samples SS-109A-1 and SS-109B-2 were collected from the till strata underlying the sands. Much greater quantities of benz(c)phenanthrene, chrysene and benz(a)pyrene were found in the sands overlying the tills than in the tills themselves. Chrysene measured in the sand overlying the till at a depth of 50 feet in Boring 9 was 474.5 μg/gm, and benze(a)pyrene was measured in the same soil sample at 6.9 μg/gm. Both of these compounds were below the detection limits in the till stratum underlying the sand. Benz(a)pyrene and chrysene were also detectable in the sand stratum at a depth of approximately 32 feet overlying the upper till stratum in Boring 9. Concentrations of these two compounds were also below detection limits in the till underlying this sand stratum. The quantification of polynuclear organic materials deep in the soil column south of the site is one of the significant findings of this study. The data indicate that the polynuclear organic materials are concentrated above the till strata and that polynuclear organic materials have moved below the upper till stratum in the glacial soils in this area. The data also indicate that the polynuclear organic materials have not moved to the deeper portions of the soil column beneath the site at least in the areas sampled by Borings 1, 2 and 5.

Midwest Research Institute's report on the eleven soil samples analyzed prior to the Phase I Report, including a discussion of analytical procedures, a summary of results and appendices containing the thin layer chromatographic screens and the gas chromatograms of the quantified extracts, is included in Appendix C of the Phase I Report. Midwest Research Institute's report on the five soil samples analyzed after publication of the Phase I Report is included in Appendix A of this report.

GEOLOGIC INVESTIGATIONS

The summary of geologic investigation methods and resulting data has been divided into discussions of glacial drift and bedrock geology.

Glacial Drift Geology

The information collected in the early portion of the study led to the conclusion that the glacial drift stratigraphy generally consisted of a complex arrangement of alternating strata of glacial till and more coarse alluvium overlain by peat deposits running north-south through the central portion of the study area. The logs from the soil borings and monitoring wells placed in the latter stage of the study along with soil borings and well logs from other sources provided additional information regarding the nature and extent of the drift stratigraphic units.

The surficial material in the lowland portions of the site and surrounding area is peat and muck, while the surficial material on the higher ground is alluvial sands and gravels. The surficial unit is referred to as the upper glacial drift unit in this report. These surficial materials are underlain by a till unit from the Des Moines Lobe glacial advance. This till unit is thickest under the peat, especially under the two storm water storage ponds that have been constructed in the area. It has a lean clay texture in the west-central portion of the study area near Boring 15, grades gradually into a sandy clay to the east in the vicinity of Boring 11, grades to a silty sand at the eastern edge of the study area in the vicinity of Boring 16, and grades to a sandy clay to the south near Boring 7. Its thickness generally varies from 2 to 5 feet over the area covered by the soil borings.

This till unit is underlain by a sequence of sands and gravels which seems continuous over the study area. The thickness of the sequence varies from 15 to 48 feet, but is generally about 20 feet. There are numerous silty and clayey lenses in this stratum, but none are deemed extensive enough to greatly inhibit vertical or horizontal flow. This unit is referred to as the middle drift aquifer in this report.

The remaining portions of the drift above bedrock is a sequence of silt, clay and sand. The clays appear to underly the peat. To the east and west, these grade into silts and sands separated by sand strata. This basal till and outwash has been combined into one drift unit for the purposes of this report and is referred to as the lower drift. The total thickness of this sequence varies from 12 to 45 feet with an average thickness of about 20 feet.

Cross-sections showing the assumed general glacial drift stratigraphy are shown in Figures 2 and 3. The locations of these two cross-sections are shown in Figure 4. The cross-sections show the complexity of the glacial drift stratigraphy in the study area. The undulations of the till/outwash contacts both in the north-south and in the east-west directions are extreme and greatly complicate an accurate quantification of glacial drift ground water movement.

Bedrock Geology

The stratigraphy of the bedrock underlying the area is complicated by the presence of buried bedrock valleys of varying depth and extent that cut through one or more of the upper bedrock units. Since it is important that the stratigraphy of the various bedrock units be well understood, the characteristics of the various bedrock units and the assumptions made about them will be discussed in detail. The general geologic column in the study area is shown in Figure 5.

Perhaps of greatest importance is a description of the contact between the glacial drift and the uppermost bedrock unit. In general, the upper bedrock unit over the study area is the Platteville limestone. In the Twin City Basin, the Platteville is comprised of three members. These are, from bottom to top, the Mifflen, a very thin and crinkly-bedded limestone about 11 to 13 feet thick; the Hidden Falls, an argillaceous dolomite limestone about 6 feet thick; and the Magnolia, a microgranular dolomite limestone or calcareous dolomite about 8 feet thick (Austin, 1969; Weiss and Bell, 1956). The thickness of the Platteville is a maximum of 31 feet in the area; however, it has been eroded to varying extents over the area.

Underlying the Platteville limestone is the Glenwood shale. This unit is a greenish-gray or olive-gray fissile fossiliferous shale containing scattered coquinoidal limestone beds (Austin, 1969). It has a sharp, non-erosional contact with the Platteville, while its lower boundary is gradational into the St. Peter sandstone. In the study area, it has a thickness of approximately 3 feet.

The contours of the Platteville-Glenwood contact over the study area are shown in Figure 6. The contour pattern was determined by the elevation of the base of the Platteville limestone from various well logs in the vicinity. This contact was used because it has a distinct non-erosional surface easily distinguished by well drillers and because the upper surface of the Platteville has been eroded over most of the study area. The Platteville-Glenwood contact is generally flat-lying, but there are several structural features to it. To the southeast, it appears that the monoclinal flexure observed elsewhere in the metropolitan area is encountered. This flexure continues to the northeast to the general vicinity of St. Anthony Falls (Olsen, per. com.). East of the study area is a slight anticline with a maximum rise of about 10 feet. In the vicinity of the study area and to the west, the Platteville-Glenwood contact slopes to the east in conformance with the basin structure of the Twin Cities area.

It is believed that the preglacial bedrock outcrop in the study area was either Decorah shale or Galena limestone (Olsen, per. com.). The Platteville has been eroded to varying degrees in places, and in other places it has been observed that all of the Platteville is present. All observation wells and borings placed for this study that extended to bedrock encountered 1 to 2 feet of limestone rubble above the Platteville. This may be the result of in-situ weathering or of basal glacial transport.

An extensive inventory was made of available well logs in the study area vicinity to determine the thickness of the Platteville. The results are shown in Figure 7. It can be seen that the Platteville thickenss in the study area ranges from 0 to over 31 feet. Most of the area southeast of the site appears to lie in an erosional channel where the Platteville thickness decreases to zero near the intersection of the proposed Louisiana Avenue Extension and the Chicago, Milwaukee, St. Paul and Pacific Railroad. The Platteville is likely missing in the remainder of this channel to the south. The log of the Methodist Hospital well and the extrapolated elevation of the Glenwood-St. Peter contact indicates that the full thickness of St. Peter sandstone is likely present at the location of this well. Although the log indicates that only glacial drift overlies the St. Peter, it can be reasonably assumed that a small amount of Glenwood is between the glacial drift and the St. Peter, since the upper part of the St. Peter is so erodible it would likely have been removed if the overlying Glenwood was not present. Therefore, it is presumed that the St. Peter does not subcrop in this erosional channel.

There is evidence of another erosional channel in the Platteville just east of the study area. This channel generally seems to run from the area near Central Junior High School to the intersection of Excelsior Boulevard and Highway 100. From the well logs and the information in Figure 7, it appears that the entire thickness of the Platteville has been removed in the vicinity of West 36th Street and Wooddale Avenue, but that the erosion has cut only slightly into the underlying Glenwood shale. However, the log from a Minnesota Department of Transportation soil boring at the intersection of Highway 100 and Excelsior Boulevard shows a long sequence of sand and gravel deposits overlying the St. Peter sandstone. The glacial drift-St. Peter contact was at Elevation 775, about 25 feet below the extrapolated elevation of the Platteville-Glenwood contact in that area. Therefore, it is hypothesized that the Glenwood shale has been eroded completely away over a portion of the erosional channel bottom between 36th and Wooddale to Excelsior Boulevard and Highway 100, allowing the St. Peter to subcrop.

About 2 miles east of the site is a major buried bedrock valley. It underlies the Minneapolis chain of lakes and cuts through the bedrock units to the Oneota formation and perhaps into the Jordan sandstone. Because it cuts through several bedrock units, it plays an important role in the bedrock hydrology of the area. With the exception of these buried valleys, the bedrock subcrop is Platteville limestone or Glenwood shale elsewhere in the study area vicinity.

Underlying the Glenwood shale is the St. Peter sandstone. This formation is a secondary aquifer used in the area by municipal and industrial wells. The St. Peter is a light yellow or white, well-sorted, quartzose sandstone. Olsen (1976) discusses the detailed stratigraphy of the St. Peter in the Twin Cities area. Olsen notes that there are several siltstone and claystone layers in the middle and at the base of the St. Peter. These layers increase in frequency and thickness to the northwest, the inferred direction of the source material. The siltstone and claystone layers in the middle of the St. Peter are considered to be discontinuous lenses, while the siltstone and claystone layers near the base are considered to be continuous (Olsen, per. com.).

The St. Peter sandstone is underlain by an unconformity of rather high relief, and the thickness of the St. Peter, therefore, varies considerably over the Twin City area. The log from a well on the site shows the St. Peter thickness to be 165 feet. This is in agreement with other well logs sited by Olsen (1976) and with logs from municipal and industrial wells in the vicinity. Therefore, the St. Peter has been assumed to be 165 feet thick throughout the study area for the purpose of this study. The thickness of the basal siltstone and claystone layers of the St. Peter was reported to be 55 feet thick at the 29th Street and Idaho Avenue well field. This is ref. in general agreement with well logs referenced by Olsen (1976) which report their thickness to be in the range of 32 to 50 feet. The basal siltstone and claystone strata were assumed to be 55 feet thick for this study.

The St. Peter is underlain by the Prairie du Chien group. This is comprised of the Shakopee and Oneota dolomites and is characterized by frequent fractures, joints and solution cavities. The Prairie du Chien is underlain by the Jordan sandstone, a coarse to medium quartzose sandstone. Because there is no aquitard separating these units, the Prairie du Chien and Jordan are considered to be one hydrologic unit. Together they comprise a major bedrock aquifer in the Twin City area. Their thickness was taken to be 244 feet for this study.

The Jordan is underlain by the St. Lawrence formation, an argillaceous dolomite about 65 feet thick which acts as an aquiclude in the bedrock hydrology of the area. Beneath the St. Lawrence, there are several minor aquifers. These include the Ironton sandstone, Galesville sandstone, and the coarser members of the Franconia sandstone. Associated with these are several aquitards consisting of the Eau Claire sandstone and the finer members of the Franconia sandstone.

Below these aquifers and aquitards are the Cambrian Mt. Simon sandstone and the pre-Cambrian Hinckley sandstone. Together, these constitute another aquifer in the Twin City Basin. They are both medium to coarse grained sandstones and together have a thickness of 263 feet. Sunde (1974) found five wells that penetrated these formations in the vicinity of the study area. These are St. Louis Park Municipal Wells 11, 12 and 13; a well drilled for the railroad; and a well on the site. Investigations for this study did not identify any other wells penetrating these formations in the area.

GROUND WATER MOVEMENT INVESTIGATIONS

The purpose of this subsection is to summarize the general methods and data used to quantify the movement of ground water laterally through the glacial drift and bedrock and vertically between the glacial drift and upper bedrock unit and between the upper and lower bedrock aquifers. The discussion of ground water movement investigations has been divided into glacial drift studies and bedrock studies.

Glacial Drift Ground Water Movement

The directions and rates of ground water movement in the glacial drift through the study area were determined using data from monitoring wells and soil samples. A total of nineteen wells and piezometers were placed during this study. Eleven of these were placed in the middle drift aquifer, six at the base of the glacial drift, one in the Platteville limestone, and one in the St. Peter sandstone. The location of these wells and piezometers are shown in Figure 8.

Wells 1 through 10 were placed during the portion of the study leading up to the Phase I Report. As shown in Figure 8, three of these wells are located on the site and six are located around the site with two tiers of wells to the south. Wells 11 through 17 were placed during the latter phase of data collection activities on the project. These wells were concentrated in the area southeast of the site to better identify the direction of ground water movement from the area of high phenolic concentration that was defined in the earlier portion of the study.

Well 1 was placed into the Platteville limestone. Wells 2, 3, 5, 6, 7, 8, 9, 10, 11 and 12 were placed into the middle glacial drift aquifer. Well 13 was placed at the base of the middle drift aquifer at the location of Soil Boring 9. The soil was visibly saturated with creosote-like material and elevated polynuclear organic concentrations were measured in the soil samples collected from the zone where the screen for Well 13 was placed. Wells 15, 16 and 17 were placed at the base of the lower drift just above bedrock. These wells were used to measure piezometric levels in the lower glacial drift to assist in defining aquifer interaction. Well 14 was placed into the St. Peter sandstone. This well was double-cased through the glacial drift, Platteville, Glenwood and into the St. Peter and was used to obtain data on the piezometric level in the St. Peter sandstone beneath the area of known high phenolic concentrations in the glacial drift. In addition to the sixteen monitoring wells placed on the project, three small diameter piezometers were placed at the locations of Soil Borings 15, 16 and 17 to provide information on the ground water levels at the locations of these borings. These piezometers were placed at the base of the lower drift near the bedrock contact. Several of the wells were "nested" with one well in the nest screened in the middle drift aquifer and a second well or piezometer in the nest screened in the lower drift.

The monitoring wells placed for this study were constructed according to the Minnesota Water Well Construction Code, except that the wells were not chlorinated after development. Each well was constructed of 4-inch diameter black steel pipe with 3 to 5 feet of stainless steel well screen. A cross-section through a typical well is shown in Figure 9. The elevation of the top of the well, the elevation of the bottom of the well screen and pertinent data regarding the soils encountered during well placement are summarized in Table 2.

Water levels in the sixteen monitoring wells placed for this study were measured on approximately a monthly basis beginning at the time each well was completed. The fluctuations in ground water levels at each well are summarized in Figures B-1 through B-13 contained in Appendix B of this report. Where ground water monitoring wells were nested, the ground water hydrographs for wells in the nest are plotted on a single figure to more easily compare the piezometric fluctuations in the higher and lower units and to more easily compare the differences in piezometric levels between the various units.

In general, the piezometric levels in the middle drift aquifer declined during 1976 and the first two months of 1977, then began to recover during March, April, May and June of 1977 due to precipitation that occurred during that period. Ground water levels in the Platteville limestone are measured by Well 1 and ground water levels in the St. Peter formation are measured by Well 14. The data from Well 1 indicate that the piezometric level in the Platteville decreased approximately 3 feet between May 1976 and June 1977. Data from Well 14 indicate that piezometric levels in the St. Peter are from 12 to 18 feet below piezometric levels in the middle drift aquifer. Piezometric levels in the St. Peter fluctuate as much as 1 to 2 feet per day due to pumping from this formation.

Ground water fluctuations in the lower glacial drift are illustrated by the hydrographs from Wells 15, 16, 17 and from the three piezometers, P-1, P-2, and P-3. The data from the short period that the wells and piezometers in the lower drift were in place indicate that piezometric levels at the lower drift/bedrock contact follow the same general pattern as piezometric levels in the middle drift. Levels at the base of the lower drift, however, are approximately .5 to 1.5 feet below levels in the middle drift in the well nests, indicating the potential for downward movement from the middle drift aquifer to the base of the lower drift.

From the measured fluctuations in piezometric levels, the piezometric gradients in the different stratigraphic units were mapped. These maps were used to determine the directions of lateral and vertical flow in these units and, along with the characteristics of the various drift units, they were also used to define the rates of ground water movement in the drift.

In the Phase I Report, the permeabilities of samples from the various drift units were reported. These permeabilities were based on applying Hazen's approximation to the grain-size distribution of samples collected from the soil borings. In the latter phase of the investigation, the permeabilities of the various drift units were further investigated using samples from the early borings. However, soil samples from several stratigraphic units of interest had been used for analysis of residual hydrocarbons and were, therefore, not available. To provide the needed data, three additional soil borings were placed and the grain-size distributions of eight samples from those samples were determined. Permeabilities were again estimated using Hazen's approximation and compared with the approximation methods of Freeze (1969) and Masch and Denny (1966).

All permeability data for the various glacial drift units are listed in Table 3. The grain-size distributions show that the glacial outwash and ice contact deposits range from a fine sand to a coarse gravel. This variation represents a potential range in permeabilities of approximately four orders of magnitude. The grain-size distributions also show that the till units range from fine silty sand to sandy clays which represents a range of permeabilities of approximately three orders of magnitude. Thus, the range of permeabilities in the glacial soils is approximately seven orders of magnitude from permeabilities of approximately 10 cm/sec for the coarse gravels to permeabilities of 10^{-6} cm/sec for the sandy clays.

The permeabilities used in the analyses of ground water movement through the glacial drift were selected from the permeabilities in Table 3. The assumed permeabilities for the till aquitard materials are:

Till Material	Permeability (cm/sec)
Silty Sand	5×10^{-4}
Clayey Sand	1×10^{-4}
Silt	5×10^{-5}
Lean Clay	1×10^{-6}

Since the permeabilities of the aquitard units are an important factor in vertical ground water movement, it was found convenient to define a term called "resistivity" as the thickness of the aquitard unit divided by the permeability. The "total resistivity" is defined as the sum of the resistivities of all materials encountered in a vertical direction through the aquitard unit. Total resistivities for the lower drift were computed at the location of fourteen monitoring wells and soil borings. The mean value of the total resistivities at those fourteen locations was 5.3×10^6 sec with a standard deviation of 3.8×10^6 sec. Since the total resistivity of the lower drift seems to be reasonably uniform, it was assumed to be constant and equal to 5.3×10^6 sec over the study area.

Six grain-size distributions were used to estimate the permeability of the middle drift aquifer. Four of the distributions were from samples collected from the western half of the study area. The four samples had a mean permeability of 5×10^{-2} cm/sec with a standard deviation of $.6 \times 10^{-2}$ cm/sec. Two distributions were from samples collected in the eastern half of the study area, both having a permeability of 1×10^{-2} cm/sec. This permeability was used for the middle drift aquifer in the eastern half of the study area. At Piezometer P-1 on the western edge of the study area, a representative sample from the middle drift aquifer had a permeability of 1×10^{-3} cm/sec. Therefore, the permeability in the middle drift aquifer was assumed to be 1×10^{-3} cm/sec on the west, 5×10^{-2} cm/sec in the vicinity of Wells 6 and 13 and then decreasing to 1×10^{-2} cm/sec east of these wells.

The vertical leakage from the middle drift was defined by applying a water balance approach to the middle drift aquifer. The rates of water movement into the middle drift laterally from the west were calculated using the piezometric gradients and permeabilities discussed above. A reasonable value for infiltration to the middle drift through change in storage in the upper drift or infiltration to the upper drift was then assumed. These represent inputs to the middle drift aquifer in the study area. The lateral movement out of the middle drift was then calculated using the gradient and permeability data. This represents one of the two outflows from the middle drift. The second output, namely leakage through the lower drift into the Platteville, was then estimated by subtracting the outflow from the sum of the inflows. The vertical leakage from the middle drift aquifer through the lower drift was checked by using the differences in piezometer levels from the nested wells and the permeabilities of the lower drift. More detail on the water balance in the glacial drift is discussed in Section IV.

Bedrock Ground Water Movement

Ground water movement in the bedrock units from the subcrop through the Mt. Simon-Hinckley were examined in this study; however, emphasis was placed on defining movement through the Platteville, St. Peter and Prairie du Chien-Jordan and on defining the interactions between the Platteville and St. Peter and between the St. Peter and the Prairie du Chien. Movement through the Mt. Simon-Hinckley and interactions between the Jordan and Mt. Simon were also evaluated.

There are no published data regarding the vertical permeability of the Glenwood shale. Initially, it was anticipated that the vertical permeability of the Glenwood could be approximated by pumping tests in the study area. In fact, pumping tests were conducted at St. Louis Park's 29th Street and Idaho Avenue well field during the early data collection activities. In this pumping test, one City well finished in the St. Peter was pumped and a second St. Peter well was used as an observation well. As discussed in the Phase I Report, the data from this pumping test best matched the nonleaky artesian type curve, indicating that the St. Peter is not being substantially recharged by leakage from the Glenwood shale within the limits of accuracy of the test. It is estimated that vertical permeabilities greater than approximately 10^{-6} cm/sec (3×10^{-3} ft/day) could have been reasonably detected with this test. The value of the storage coefficient obtained in the pumping test also indicated that the aquifer was confined. During the latter stages of the study, pumping test methods in the area southeast of the site were evaluated as a means of estimating the vertical permeability of the Glenwood shale. It was eventually concluded that pumping tests would not yield data of sufficient accuracy to measure the permeability. The lowest permeability that could be measured in a pumping test is estimated to be on the order of 10^{-6} cm/sec to 10^{-7} cm/sec due to background fluctuations and other factors. With a differential of 18 feet between the St. Peter and the lower drift, permeabilities of this order of magnitude would have led to seepage rates on the order of 6 to .6 ft/year. The water quality of the St. Peter, as measured by Well 14, indicates that seepage is likely not occurring at this rate. More complete information behind the decision not to use pumping tests is presented in Appendix E.

For the purposes of the ground water investigations in this study, the vertical permeability through the Glenwood was estimated using three data sources. The first data source was the pumping test described in the Phase I Report. Although the leakage and resulting vertical permeability through the overlying Glenwood shale could not be quantitatively determined, due to the inherent limitations on pumping tests in this area, the test did indicate that permeability of the Glenwood shale was less than 10^{-6} cm/sec.

The second source of data was other information published on the permeability of shale. Shale itself is typically very impermeable with the actual permeability of a shale unit nearly always a function of fracturing, especially in thin shale strata such as the Glenwood. Freeze (1969) lists the permeabilities of various sedimentary units in south-central Saskatchewan including several shales. Their permeabilities ranged from 1.7×10^{-7} to 5.7×10^{-10} cm/sec (4.8×10^{-4} to 1.5×10^{-6} ft/day). Thus, it can be reasonably stated that shale is extremely impermeable unless it is fractured, in which case the permeability will increase substantially. A literature search was conducted to locate the available information regarding fracturing of the Glenwood. Norvitch (1973) describes the Glenwood as "bluish-gray to bluish-green; generally soft but becomes dolomitic and harder to the east." The water-bearing characteristics of the Glenwood are defined by Norvitch (1973) as "confining bed; locally some springs issue from the Glenwood-Platteville contact along the river bluffs." Sunde (1974) reports that the Glenwood shale would normally be quite impermeable; however, it reflects in many cases the fracturing of the overlying Platteville limestone. Information from the Minnesota Geological Survey (Olsen, per com.) indicates that fractures in the Glenwood only reflect major fractures in the Platteville. Minor fractures in the Platteville have been observed to terminate before completely penetrating the Glenwood.

Along with the data collected during the pumping test at the 29th and Idaho well field, there is additional data to indicate that the Glenwood shale is quite impermeable in the study area. Water samples from the St. Peter well constructed during this study exhibited either undetectable or very low concentrations of phenolics below the heavily contaminated basal glacial drift area south of the site. The measured head differential between the basal drift and the St. Peter is 12 to 18 feet in this area. If the Glenwood shale was fractured, the permeability through these fractures would approximate unity and contamination would likely be detectable in the St. Peter well. It must also be remembered that fracturing in the Glenwood shale is not analogous to fracturing in a more soluble material such as the overlying Platteville limestone. While the width and, therefore, the water-carrying capacity of fractures in a limestone material will logically tend to increase as flow occurs through the fractures, flow through fractures in a shale material will logically tend to decrease as clays and silt-size materials are carried through the fractures and pushed into the underlying St. Peter formation. For the purposes of this study, a permeability of 10^{-8} cm/sec (3×10^{-5} ft/day) was assumed. This is considered to be the highest probable permeability for this formation.

* CONFIRMS AQUITARD

The vertical and lateral permeability of the Platteville is also unknown. Although its limestone matrix is quite permeable, the information is known to be eroded and weathered, with numerous horizontal and vertical joints and fractures that have become solution channels. Due to the unknown pattern of these solution channels in the study area, the Platteville was assumed to have an infinite vertical and lateral permeability for this study.

The transmissivity (permeability multiplied by aquifer thickness) of the St. Peter aquifer was determined by a pumping test at the St. Louis Park's 29th Street and Idaho Avenue well field to be 25.0 cm^2/sec (17,400 gal/day-foot). This represents a permeability of 5×10^{-3} cm/sec (14 ft/day) and is well within the range of permeabilities for the St. Peter formation given in Norvitch (1973). The vertical and horizontal permeabilities of the St. Peter were assumed equal. Porosity of the St. Peter was assumed to be 30% based on data from the U.S. Corps of Engineers (1939).

As discussed previously in this section of the report, the Prairie du Chien-Jordan is separated from the St. Peter aquifer by siltstone and claystone strata at the base of the St. Peter. These are considered to be an aquitard (Olsen, per. com.). The vertical permeability of this aquitard was estimated using data from a pumping test described in the Phase I Report. This test was conducted at St. Louis Park's 29th Street and Idaho Avenue well field. From this test, the vertical permeability was found to be 2×10^{-6} cm/sec (0.006 ft/day). This value was initially used for the vertical permeability. This is one-fifth the value at the bottom of the range for vertical permeability of the St. Peter reported in Norvitch (1973); however, the range of values in this reference is for the aquifer portion of the St. Peter.

Because there is no aquitard separating the Prairie du Chien and Jordan, these two formations were considered to be one aquifer, although their permeabilities differ. An average permeability of 1.6×10^{-2} cm/sec (50 ft/day) as given in Norvitch (1973) was used for the Prairie du Chien-Jordan aquifer in this study. The vertical permeability was assumed equal to the horizontal permeability. The porosity of the Jordan was assumed to be 20% based on data from the U. S. Geological Survey (Hult, per. com.). The porosity of the Prairie du Chien group is unknown and likely highly variable. For estimating purposes, a porosity of 20% was assumed for the entire Prairie du Chien-Jordan aquifer.

The Jordan aquifer is separated from the Mt. Simon-Hinckley aquifer by the St. Lawrence, Franconia, Ironton-Galesville and Eau Claire units. In estimating the time for leakage to pass from the Jordan aquifer to the Mt. Simon, only the Eau Claire was considered due to the lack of data for the other intermediate aquitards. A permeability 10^{-10} cm/sec (3×10^{-7} ft/day) was assumed for the Eau Claire (Norvitch, 1973). A thickness of 87 feet and a porosity of 10% were also assumed.

The Mt. Simon and Hinckley were considered to be one aquifer, although their permeabilities differ. An average permeability of 3.5×10^{-3} cm/sec (10 ft/day) as given by Norvitch (1973) was assumed for the Mt. Simon-Hinckley aquifer and the porosity of the combined aquifer was estimated to be 10%.

The hydrogeology of the bedrock system in the study area is complex. The complexity is caused by a number of factors including:

a. the large number of pumping wells in the area. Many of these wells are uncased through more than one aquifer and, therefore, draw water from multiple aquifers when pumping. Since many of these wells are pumped only on a seasonal (winter/summer) basis, the potential exists for changing conditions on a seasonal basis. In addition, use of many of the industrial and municipal wells, especially those finished in the upper bedrock aquifers, are being phased out. Thus, the potential also exists for changing conditions over the period of time studied in this report.

b. the wells in the area that are uncased through various formations. When not in use, these wells provide pathways for the movement of water from an aquifer of higher piezometric level to aquifers of lower piezometric levels. These levels include wells that are no longer being used and wells that are only periodically pumped. Undoubtedly there are wells of this type that are unrecorded.

c. the bedrock valleys that cut through the area.

To collect as much data as possible on the factors that effect ground water movement, a field survey was carried out to locate existing industrial, municipal and private residential wells. The area of major emphasis was south and southeast of the site due to the elevated phenolic concentrations found in the glacial drift in this area. The review of existing well logs by Sunde (1974) was used as a starting point in the field survey. Field interviews were carried out with industrial representatives and private residents in the area of interest. The locations of the wells that were located in the field survey are illustrated on Figure 10.

The following wells identified by Sunde (1974) in his survey of well logs could not be located in the field survey. The alpha-numeric designations are the same as used by Sunde (1974).

a. Milwaukee Railroad - (no designation in Sunde) Mt. Simon-Hinckley well cased to the first bedrock contact.

b. 3612 Alabama - (B-14) St. Peter well cased to first bedrock contact.

c. Strom Block Company - (B-11) St. Peter cased to the first bedrock contact and (A-25) Jordan well cased into the siltstone stratum at the base of the St. Peter sandstone.

d. Blacktop Service Company - (A-21) Prairie du Chien-Jordan well cased into the siltstone stratum of the St. Peter. Sunde (1974) indicates this well may be sealed.

Wells not identified by Sunde (1974) in his survey of available well logs that were located during the field survey for this report include:

a. Mill City Plywood Company - Representatives of Mill City Plywood indicated there is a well approximately 60 feet deep on their property. The well water smelled of coal-tar and the well was never used. Sixty feet of depth puts the well screen in the lower glacial drift. The well head is visible, but the pump is no longer in place.

b. Lakeland Door Company - The well is reportedly 90 feet deep and is finished in the Platteville. The well has not been used for the last 15 to 20 years. A log for this well was obtained from the well driller and one is also available from the Minnesota Geological Survey. Representatives of the Lakeland Door Company cannot recall a coal-tar odor from this well.

c. Ace Manufacturing Company - 3825 Edgewood Avenue - The owner of Ace Manufacturing Company indicated that there is a well on the property, although it has not been used for a number of years. The well head is visible, although the pump has been removed. No log is available for this well.

d. Hartman Well - A well is located at the Hartman residence at [redacted]. The well has a pitcher pump and was sampled for this study. The owner recalls that the well is approximately 160 feet deep. It has not been used for about 10 years. The resident could not remember ever detecting a coal-tar smell or taste in the well water.

e. Methodist Hospital - This well is finished into the St. Lawrence formation. The well log indicates 270 feet of casing with glacial drift to 94 feet, St. Peter sandstone to 257 feet, Shakopee limestone to 377 feet, Jordan sandstone to 466 feet, and approximately 20 feet of open hole into the St. Lawrence formation.

Other wells in the area for which logs were located that had not been reported previously include:

a. Rogers - 7401 Walker Street - This is a 4-inch diameter 160-foot deep well placed into the St. Peter sandstone. A well log is available for this well from the Minnesota Geological Survey. The well is cased to the Platteville and the open hole extends 2 feet into the St. Peter.

b. Lakeland Door Company - According to a well log available from the Minnesota Geological Survey, a second Platteville well is located at the Lakeland Door Company. This well is shown to be 85 feet deep.

c. Terry Excavating - 3326 Republic Avenue - According to a local well driller, there is a 112-foot deep, 4-inch diameter well located along Republic Avenue immediately east of the site. The well log shows 80 feet of drift, 20 feet of Platteville and 12 feet of St. Peter. The well is cased to the first bedrock contact and, thus, represents a pathway for movement between the Platteville and the St. Peter.

d. Old City Well No. 1 - This well is located at 6021 West 36th Street and was drilled in 1932. The well extends into the St. Lawrence shale and is cased into the top 60 feet of the Shakopee limestone. The well reportedly was abandoned after placement because of a coal-tar taste to water from the well.

Due to the complexity of the bedrock hydrogeology brought about by the buried valleys and uncased wells, rather rigorous mathematical or analog tools are required to adequately predict piezometric levels in the various bedrock aquifers under existing or assumed future conditions. Fortunately, the development of the mathematical model necessary to predict ground water gradients in a multi-level leaky aquifer system such as exists beneath the study area was proceeding by Heitzman and Strack (Heitzman, unpublished M.S. thesis) at the University of Minnesota's Department of Civil and Mineral Engineering concurrently with the investigations discussed in this report. The methodologies developed by Heitzman and Strack model a three-dimensional multi-aquifer system composed of three confined aquifers, each overlain by a leaky aquitard with the lowest aquifer underlain by an impermeable base. The model assumes that each hydrologic unit is of constant thickness and that the pressure above the uppermost aquitard is constant and equal to the pressure in all aquifers at an infinite distance from the modeled area. There is provision for both point and line sources and sinks which can be identified either by a pumping rate or by a piezometric level. Point sources and sinks may be uncased or cased through any combination of the three aquifers. The piezometric level at desired locations in all three aquifers are determined by applying standard leaky aquifer ground water equations and continuity to the multi-level aquifer system. The method has been computerized to handle the complexities of the hydrogeologic systems in the study area and to obtain the piezometric levels at any lateral or vertical point in the system.

The boundary conditions for the model were identified where the piezometric levels and wells are known with some certainty. The piezometric boundaries were based on the piezometric information in Norvitch (1973) and the geologic information in Hogberg (1970) and Payne (1965). Norvitch (1973) found that the piezometric levels for the Prairie du Chien-Jordan aquifer in the study area vicinity changed uniformly and dropped 7 feet from winter, 1965 to winter, 1970. It was, therefore, assumed for this study that historical and future changes in pressure distribution would also be uniform and that the pressure differences between the St. Peter and Prairie du Chien-Jordan aquifers would remain approximately the same as they are now.

The piezometric boundary conditions were simulated by means of line and point sources and sinks. Their location and associated piezometric levels are summarized in Figure 11. Without the influence of wells in the study area vicinity, the direction of flow in both the St. Peter and Prairie du Chien-Jordan aquifers is generally to the east. This was found to be satisfactorily modeled using the eastern and western boundary conditions shown in Figure 11.

The western piezometric boundary used for the Prairie du Chien-Jordan aquifer is a line of recharge underlying Grays Bay of Lake Minnetonka. Norvitch (1973) shows this to be a stable feature with a constant piezometric level throughout the year. The Prairie du Chien-Jordan in this area underlies a possible buried bedrock valley that cuts into the St. Peter, as shown by Hogberg (1970). The piezometric level in the Prairie du Chien-Jordan along this line was assumed at Elevation 912. The eastern piezometric boundary condition is located at approximately the western boundary of the buried bedrock valley near the Minneapolis city limits. Norvitch (1973) shows that the piezometric level along this boundary to be approximately at Elevation 825 in the winter and at Elevation 800 in the summer. These were the piezometric levels used for the boundary conditions in the winter and summer cases studied.

The western piezometric boundary condition for the St.Peter aquifer is the Elevation 900 piezometric contour shown in Norvitch (1973). This value was used for both the winter and summer cases since the overlying recharge zone and underlying Prairie du Chien-Jordan aquifer have quite constant piezometric levels throughout the year. The location of the eastern piezometric boundary for the St. Peter is the same as the location of the eastern boundary for the Prairie du Chien-Jordan since this is approximately where the overlying bedrock confining layer ends and where the St. Peter begins to be eroded. The winter piezometric level in the St. Peter at this eastern boundary is shown to be at Elevation 825 by Norvitch (1973). This is the same as the winter piezometric level in the Prairie du Chien-Jordan, indicating that the piezometric levels in the St. Peter is a major factor in determining piezometric levels in the Prairie du Chien-Jordan. Since the Prairie du Chien-Jordan is more heavily pumped in the summer than is the St. Peter, the summer piezometric level at the eastern boundary was assumed at Elevation 810, 10 feet higher than in the Prairie du Chien-Jordan.

The uppermost aquifer used in the model was the lower drift/Platteville. Initially, conditions were assumed for this aquifer, but it was found that the changes in the piezometric levels in the lower drift did not influence piezometric levels in the underlying aquifers to any noticeable degree because of the impermeability of the Glenwood aquitard. The piezometric level in the drift aquifer and the piezometric level at infinity were assumed to be at Elevation 890 which represents an average piezometric level in the lower drift in the study area vicinity.

The distribution of piezometric pressure in the bedrock aquifers is affected by pumping from municipal and industrial wells between the western and eastern boundary conditions. An investigation was conducted to locate wells that would affect piezometric levels in the large area between the boundary conditions. These wells are shown in Figure 11. Some wells in this area are pumped at about the same rate on a year-round basis. Others, however, are pumped only in the summer for air conditioning purposes or have increased pumping rates at that time. Different summer and winter pumping rates were used for these wells in the computation of summer and winter piezometric levels.

Wells in the area are generally not pumped continuously. Typically, the wells are pumped for a portion of the day, but are idle for the remaining portion. Therefore, for modeling purposes, the pumping rate of each well was defined by dividing the total monthly volume of water pumped by the number of minutes in a month to obtain an average monthly pumping rate. Since the time scale for the model is on the order of months or even seasons, this averaging of pumping rates was considered satisfactory to obtain a picture of piezometric gradients.

Three wells in the immediate study area are known to be no longer used and are uncased through several important aquifers. These are the Mt. Simon-Hinckley well on the site, the Terry Excavating well and the Midco Register well. Each of these wells, therefore, was assumed to act as a recharge well. The Hinckley well on the site penetrates several uncased aquifers, each with different heads, permitting flow between the Prairie du Chien-Jordan and the Mt. Simon-Hinckley aquifers. The Terry Excavating and Midco Register wells are open a significant distance into the St. Peter, but cased only to the Platteville, thus permitting leakage from the lower drift/ Platteville into the St. Peter.

Several existing wells in the area were not included as boundary conditions in the model. These were:

a) St. Peter Well on the Site - The log for this well from the Minnesota Geological Survey indicates it is 91 feet deep. According to the log, this is the bottom of the Platteville and the top at the St. Peter. Since the Glenwood is not included in the log, it is unclear whether the well is finished to the top of the Glenwood or to the top of the St. Peter. The static water level at the time of the well drilling was 6 feet below grade or approximately at Elevation 884. This is comparable to the piezometric level in the lower glacial drift or Platteville. Since the St. Peter has a piezometric level approximately 10 to 18 feet below that in the Platteville, it would be reasonable that if the well extended through the Glenwood, the static water level in the well would be lower than 6 feet below the ground surface. Also, the log indicates that the well does not penetrate into the St. Peter, so very little area is available for recharge. It was, therefore, concluded that this well does not represent a potential recharge well.

b) Railroad Mt. Simon-Hinckley Well - The railroad Mt. Simon-Hinckley well is reportedly cased only to the Platteville. If this is the case, this well would produce flow between the St. Peter and Mt. Simon-Hinckley and between the Prairie du Chien-Jordan and Mt. Simon-Hinckley. This well was not used for two reasons. First, it would seem unlikely that the railroad would place a Mt. Simon-Hinckley well cased only through the drift. Second, if the well was drilled to the Mt. Simon-Hinckley but left open through the St. Peter, the erodible portion of the upper St. Peter would be carried down the well effectively plugging it.

c) Strom Block Company Well, 6425 Goodrich Avenue - According to the log obtained from the Minnesota Geological Survey, this well is cased to within 19 feet of the base of the St. Peter, then open-hole through the bottom 19 feet of the St. Peter to the base of the Jordan. The bottom 55 feet of the St. Peter is assumed to be the claystone and siltstone confining layer and it was, therefore, assumed that any recharge from the St. Peter to the Prairie du Chien-Jordan would be negligible. Since the well is not pumped, it was left out of the model. This same assumption was applied to the Blacktop well identified by Sunde (1974). This well is also cased into the basal aquitard of the St. Peter.

d) Rogers, 7401 Walker Street - The available log for this well indicates it is cased to the top of the Platteville, but only extends into the St. Peter a distance of 2 feet.

While a small amount of recharge could move from the lower drift/Platteville to the St. Peter, the very small penetration would seem to greatly limit the recharge and it was neglected in the model.

The multiple leaky aquifer model of Heitzman and Strack and the above boundary conditions were used to predict the distribution of piezometric levels in the St. Peter and Prairie du Chien-Jordan aquifers during winter and summer conditions. The piezometric gradients and the permeabilities were then used to predict flow rates and travel times in the St. Peter and Prairie du Chien-Jordan. The assumed vertical permeabilities of the Glenwood and basal St. Peter siltstone, along with the piezometric levels from the model, were used to estimate the vertical rates of leakage through these two aquitards. In addition, available data was used to generally predict ground water movement in the Mt. Simon-Hinckley and leakage to the Mt. Simon from the overlying Jordan aquifer.

GROUND WATER QUALITY INVESTIGATIONS

As discussed previously, one of the primary objectives of this soil and ground water investigation was to define the extent to which the wastes discharged from the coal-tar distillation and wood-preserving facility had affected the surficial and bedrock ground water quality. This objective took on additional significance as the soils data were evaluated and it became evident that high concentrations of coal-tar derivatives were present in the soils, especially on the southern portion of the site and in the wetland areas south of the site.

Prior to the data collected in this study, available data on ground water quality in the study area were collected entirely from the municipal and industrial bedrock wells that exist in the area. Virtually no data were available on the quality of ground water in the glacial drift in the study area. Previous investigations had indicated that water from an industrial well southeast of the site was contaminated with phenolic compounds and that most of the bedrock wells in the area periodically exhibited very low, but detectable, concentrations of phenolics.

Monitoring Wells

The locations of the various wells that were sampled as a part of this investigation are summarized in Figure 12. The symbol used to designate the well location denotes the formation into which the well terminates. The characteristics of the various wells that were sampled are summarized in Tables 2 and 4.

The wells shown on Figure 12 include the sixteen wells that were put in for this investigation, seven industrial wells that are used to varying degrees, three municipal wells that are part of the municipal water supply system for St. Louis Park and one residential well that is not being used.

The depths and other characteristics of the sixteen wells placed for this study are discussed in the subsection on ground water movement investigations and on Table 2. Most of these wells were located in the area southeast of the site to better define the area of elevated phenolic concentration originally identified earlier in the study. Well 1 is in the Platteville limestone. Wells 2, 3, 5, 6 and 7 through 12 are screened in the middle drift aquifer. The screen for Well 13 was placed 50 feet below the ground surface at the location of Soil Boring 9. The soil was visibly saturated with creosote-like material and elevated polynuclear hydrocarbon concentrations were measured at this depth. Screens for Wells 15, 16 and 17 were placed in the lower drift, typically just above bedrock. Well 14 was placed into the St. Peter sandstone. This well was double-cased through the glacial drift, Platteville, Glenwood and into the St. Peter. It was used as a sampling point to define the quality of water in the St. Peter formation beneath an area of known high phenolic concentration in the glacial drift.

Ground water samples were periodically collected from wells shown in Figure 12. More samples were collected from the wells south and southeast of the site where elevated concentrations of phenolics were identified than from the wells showing undetectable or trace concentrations. In addition to the sixteen wells placed for the study, samples were collected from the following industrial, residential and municipal wells described in Table 4.

Baum Report

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"Since gradient control..."

III-19 " The vertical and lateral permeability ..."

III-20 " As discussed previously..."

IV-22 " In summary..."

IV-23 " In the case of City St Peter..."

IV-23 " As discussed in the subsection ..."

V-2 " The ~~st~~ stratigraphy and permeability..."

Flame Industries
Midco Register (formerly Robinson Rubber Company)
St. Louis Park Wells 1, 3 and 10 at the 29th Street and Idaho Avenue well field
Sterilized Diaper Service
Minnesota Rubber Company
Burdick Grain
S & K Products (two wells)
Methodist Hospital
Hartman Residence

Ground Water Quality Data

Ground water samples were typically analyzed for phenolics which were used as a tracer for the soluble fraction of the coal-tar waste. In addition, selected samples were analyzed for biochemical oxygen demand, chemical oxygen demand, total dissolved solids, pH, copper, zinc, cadmium, lead, arsenic, total organic carbon, specific conductance, total alkalinity, total hardness, freon extractable material and benzene extractable material.

Samples collected on the project were routinely analyzed by SERCO Laboratories. In addition, one set of samples was split with the Minnesota Department of Health to form a basis for comparison between the two different analytical procedures that were used to analyze samples for phenolics during this study. In addition, two sets of samples were sent to the U. S. Environmental Protection Agency's Central Research Laboratory in Chicago, Illinois, for gas chromatography/mass spectroscopy analysis. Of particular interest in the EPA's analyses were measurement of polynuclear aromatic hydrocarbons* and hydroxolated aromatic hydrocarbons.

The ground water quality data collected for this study are summarized by station and by parameter in Tables 5 through 7. The data were used to develop the general picture of ground water quality in the study area presented in Section IV of this report. Each well was typically pumped from 15 to 20 minutes prior to sampling to help establish equilibrium conditions before the sample was collected.

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*Polynuclear aromatic hydrocarbons referred to by the EPA laboratory are the same class of compounds referred to as polynuclear organic materials by Midwest Research Institute in their analyses of soil samples.

The analytical procedures and detection limits used by SERCO Laboratories are summarized in Appendix C. The phenolic analyses by the Minnesota Department of Health were carried out using a different method than the analyses by SERCO Laboratories. A review of the differences between the two analytical procedures may explain the differences in the phenolic concentrations in the samples split between these two laboratories. SERCO Laboratories uses the 4-aminiantipyrine colormetric method as described in the Fourteenth Edition of Standard Methods. The Minnesota Department of Health uses the manual 3-methyl-2-benzothiazolininone (MBTH) colormetric procedure. This method was adopted for use by the Department of Health from work by Frestad (1969). Both the MBTH and 4-aminoantipyrine methods are colormetric procedures for measuring phenolic concentrations after preliminary distillation. Both reactants form a colored complex with phenolic compounds which is then measured on a spectrophotometer. The basic difference between the two methods is the broader range of phenolic compounds measured by the MBTH Method. This method, for example, is believed to measure the para-substituted phenolics. In contrast, the 4-aminoantipyrine procedure does not detect these compounds. Discussions with representatives of the Minnesota Department of Health have indicated that the MBTH Method was adopted for use in studies of the St. Louis Park water supply because of its ability to better quantify parameters associated with coal-tar waste. It is not used routinely, however, by commercial laboratories and is not used by SERCO Laboratories.

CAN'T BE REPRODUCED.

In reviewing the split sample data, the differences indicate that the MBTH Method is likely detecting more compounds than the 4-aminoantipyrine procedure. This was substantiated by additional analyses carried out by the Minnesota Department of Health. The Minnesota Department of Health laboratory randomly selected three of the previously analyzed samples and reran them using both the MBTH and the 4-aminoantipyrine methods. This data verified that lower values were detected using the 4-aminoantipyrine method.

The analytical procedures used by the Environmental Protection Agency as well as the data from the analyses of samples provided to them, are contained in their laboratory reports included in Appendix D to this report.

glacial drift
glacial drift

Two sets of ground water samples from the study area were transmitted to the U. S. Environmental Protection Agency's Central/Research Laboratory in Chicago, Illinois. The first set of samples was collected in February, 1977 from Wells 9, 13 and 14, and the Flame Industries' well. Analysis involved extraction of the sample three times, each time with 60 milliliters of 15% methylene chlorine/hexane solution. The extracts were then combined and concentrated to approximately 1 milliliter. Appropriate amounts of the concentrated extract were injected into a gas chromatograph. The results of the February analysis indicated that the samples from Well 14 and from the Flame Industries' well contained no detectable organics with a detection limit of 10 to 50 parts per billion. The sample from Well 9 contained organic material at a concentration of approximately 4 grams of oil per liter of water. The sample from Well 13 was found to contain a complex mixture of hydrocarbons. The extract from this sample was further analyzed using mass spectroscopy. This analysis revealed that over 50% of the sample extract consisted of polynuclear aromatic hydrocarbons. The following polynuclear aromatic hydrocarbons were identified.

naphthalene*
pyrene*
anthracene or phenanthrene*
fluoranthrene*
methylnaphthalene
acenaphthene
dibenzofuran
fluorine
benzophenanthene
benzofluoranthene

*These compounds were present in higher concentrations relative to others.

A second set of samples was collected in late May, 1977 from Wells 9, 13, 14, 17, City Well 3 and the Flame Industries' well. These samples were also extracted and the extracts analyzed by gas chromatography. Total extractable organics were detected in Well 14, the Flame Industries' well and in City Well 3 at a concentration of .05 milligrams per liter; however, no polynuclear aromatic hydrocarbons were detected at a detection limit of .03 milligrams per liter in these wells. The concentrations of total extractable organics and polynuclear aromatic hydrocarbons in the sample from Well 13 were both found to be 3,400 milligrams per liter. The concentration of total extractable organics in the sample from Well 9 was found to be 2.5

milligrams per liter; however, the concentration of polynuclear aromatic hydrocarbons in the water sample was found to be undetectable at a detection limit of .1 milligrams per liter. The concentrations of total extractable organics and polynuclear aromatic hydrocarbons in Well 17 were both measured at 1.7 milligrams per liter. The polynuclear aromatic hydrocarbons naphthalene, methylnaphthalene, acenaphthene, dibenzofuran, phenanthrene or anthrancene, fluoranthene and pyrene were identified in the sample from Well 13.

Investigation of Mt. Simon-Hinckley Well on Site

As part of the water quality investigation, the existing Mt. Simon-Hinckley well on the site was investigated. To investigate the well, the well head was first removed and the pipe and pump bowls were pulled from the well. Noticeable coal-tar material was present on the pipe below the water level at a depth approximately 40 feet below the well head. The coal-tar material became thicker with depth and the screen and bowls of the pump were clogged with coal-tar. The well was pumped at approximately 100 gallons per minute with a portable pump for approximately 100 minutes. Water samples were taken at intervals of 1 minute, 15 minutes, 30 minutes and 100 minutes, and phenolic concentrations were measured in these samples. After 1 minute of pumping the phenolic concentration was .020 mg/l, after 15 minutes the concentration was .011 mg/l, after 30 minutes the concentration was .008 mg/l, and after 100 minutes the concentration was .005 mg/l. Thus, the concentration of phenolics decreased with pumping time.

An area well driller indicated that the turbine pump in the well periodically became "gummed up" with creosote-like material during the early 1950's. Rumor has it that a spill occurred in the area and that coal-tar material traveled down the well. The company reportedly pumped steam into the well to loosen the material. This technique apparently was successful, but had to be carried out from time to time to keep the well usable. The coal tar on the draw pipe would seem to substantiate that coal-tar material did go down the well.

Also according to a well driller, a packer was placed in the well in the early 1950's. The packer consists of a rubber ring that fits tight inside the 8-inch casing. A 4-1/2 inch diameter pipe extends to the Jordan. According to the well contractor that installed the packer, it was intended to circumvent the "contaminated" portion of the aquifer and supply the company with clean water, but did not work. The casing schedule and the depth of the well, and vertical movement of water between the aquifers could not be measured during the investigation. The packer effectively blocks off the well at depths below about 260 feet.

The available data indicate that the well was constructed in 1908 and is approximately 950 feet deep. It is inferred that the total casing extends approximately 260 feet deep through the St. Peter sandstone. A 12-inch casing likely extends from the surface 73 feet through the glacial drift, a 10-inch casing likely extends from the surface 93 feet through the Platteville limestone and an 8-inch casing extends from the surface 260 feet through the St. Peter.

Ground Water Chlorination Experiments

To examine the potential effect of chlorinating very dilute coal-tar wastes, a water sample from Well 17 was oxidized with 3.58 mg/l of sodium hypochlorite. The dosage was selected to coincide with dosages used by St. Louis Park in chlorination of its water, which is treated with 25 to 32 pounds of chlorine gas per million gallons of water (Tolefsrud, per. com.). A contact period of 1 hour was used to guarantee that chlorination reactions could go to completion. Gas chromatographic analyses were made of extracts of both chlorinated and unchlorinated samples to check for the removal of phenolics and for the possible creation of chlorinated organics.

Analytical instruments used in the analyses included chromatographic columns with flame ionization and electron capture detectors. Flame ionization is one of the two methods commonly used for gas chromatography identification of volatile organic compounds. Electron capture is commonly used for analysis of pesticides, but not for identifying phenolic compounds. Chromatographic results were interpreted by comparison with known column residence times for fifteen phenolics and chlorinated compounds listed in the following table.

COMPOUNDS WHICH COULD HAVE BEEN IDENTIFIED
WITH THE FLAME IONIZATION DETECTOR*

Dichoromethane	Perchloroethylene
1,1-Dichloroethane	1,1,1,2-Tetrachloroethane
Chloroform	1,1,2,2-Tetrachloroethane
1,2-Dichloroethane	Phenol
1,1,1-Trichlorethane	_o_ - creosol
Carbon Tetrachloride	_m_ - creosol
Trichloroethylene	_p_ - creosol
1,1,2-Trichlorothane	

*Identification of phenolic compounds based on standards developed in the laboratory. Identification of chlorinated hydrocarbons was based on calibration information supplied with the chromatographic equipment.

Analyses indicated a reduction in the concentration of phenolics due to chlorination. Sample peaks could not be found at the location corresponding to the three creosols and the eleven chlorinated hydrocarbons listed in the above table, even at the most sensitive detection limits, indicating that these compounds were not present. A number of small unidentified peaks in the chromatograph, however, were observed but could not be identified with standards available in the laboratory. These may represent background noise or organic compounds. The possibility remains that chlorinated organics, such as chlorophenols, are being produced since the chromatographic column used with the flame ionization detector precluded the analysis of chlorophenols.

The question of the fate of the added chlorine is unresolved. Absence of detectable chloroform indicates that the haloform reaction for the formation of chlorinated organic compounds (Morris, 1975) did not go to completion. However, the existing data do not preclude the existence of a wide variety of chlorinated hydrocarbons which could have been formed. A series of additional tests, using mass spectroscopy, for example, will be necessary to identify more of the compounds that are present.

S E C T I O N   I V

EXISTING GROUND WATER CONDITIONS

SECTION IV
EXISTING GROUND WATER CONDITIONS

The purpose of this section of the report is to incorporate the results of the various investigations discussed in Section III into a definition of existing ground water movement and quality in the study area. This section has been divided into two subsections; one defining ground water conditions in the glacial drift and the second defining ground water conditions in the bedrock aquifers. Since the Platteville limestone formation was found to be a major factor controlling ground water movement through the glacial drift, the definition of ground water movement through this formation is included in the discussion of the glacial drift. Ground water movement through the St. Peter, Prairie du Chien-Jordan and Mt. Simon-Hinckley aquifers and the interactions between these aquifers are defined in the subsection on bedrock ground water conditions.

In general, data collected in this study, along with other available data, fit together well to conceptually describe the general ground water conditions in the drift and bedrock aquifers. As with most ground water studies, additional data would be desirable to more quantitatively define ground water conditions, especially conditions relating to the quantity and quality of ground water moving through the area. The existing data base is sufficient to locate the major area of ground water contamination and to describe the direction of ground water movement from the contaminated area through the drift and bedrock. Additional data, however, would be helpful to better quantify the rate of movement from the contaminated area as well as the quality of water in the bedrock aquifers.

EXISTING GLACIAL DRIFT CONDITIONS

As described in Section III, the glacial drift in the study area is made up of the following strata:

a. the upper drift comprised of peat and outwash,

b. the middle drift aquifer comprised of outwash and ice-contact deposits,

c. a till layer separating the upper drift and the middle drift aquifers, and

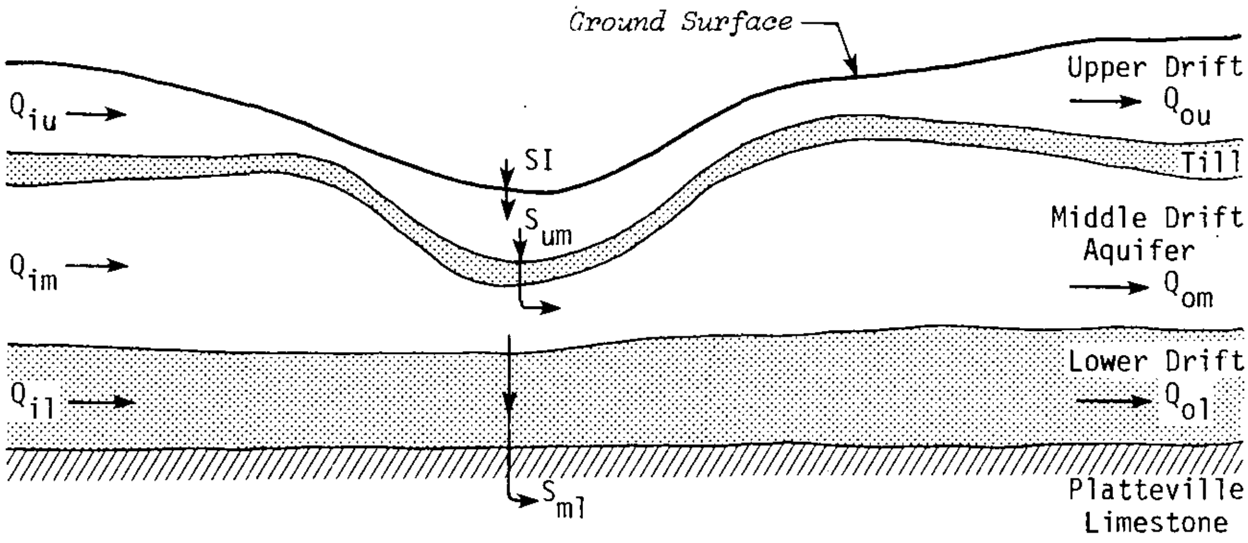
d. the lower drift which varies in permeability and overlies the Platteville limestone.

Ground Water Movement

Ground water movement through the drift was modeled using a water balance approach. The available data was used to prepare two interpretations of ground water movement through the drift. The two interpretations are similar in concept and represent two examples that likely bracket the actual ground water movement through the drift. Since the two interpretations are conceptually similar, one will be discussed in detail and the second will be discussed more qualitatively.

Due to the location of the monitoring wells in the eastern portion of the study area, the exact configuration of the piezometric contours in the middle drift aquifer could not be determined. From general information about the water table in the area, however, it is evident that the area immediately east of the site is a potential recharge area to the middle drift aquifer. The interpretation of ground water movement through the middle drift aquifer that will be discussed in detail assumes that the middle drift aquifer in this area is relatively impermeable and blocks flow through the middle drift in this area. Under this interpretation, the piezometric contours are essentially straight and parallel in the eastern portion of the area covered by the network of monitoring wells.

The various elements in the water balance are shown schematically on the following page.



SCHEMATIC OF GROUND WATER MOVEMENT

Under both interpretations, lateral inflow to the study area and outflow from the study area through the upper drift (Q_{iu} and Q_{ou}, respectively) were assumed to be negligible in comparison to the vertical seepage from the upper drift to the middle drift aquifer (S_{um}). This assumption was based on the fact that the till stratum separating the upper drift and middle drift aquifer rises nearly to the surface immediately east and west of the peat deposit that runs north-south through the study area. This effectively cuts off or greatly reduces lateral flow through the upper drift.

The piezometric levels in the middle drift aquifer during the study period were determined from the water levels recorded in Wells 2 through 13. These well hydrographs, included in Appendix B to this report, show that the piezometric levels in the middle drift aquifer generally dropped from March, 1976 through February, 1977. During this time, however, the general piezometric gradients across the study area were quite constant, indicating quite constant discharge through the middle drift aquifer. Under the first interpretation, representative piezometric levels in the middle drift aquifer for the 1976 winter period are shown in Figure 13. As shown by these piezometric contours, flow in the middle drift aquifer underlying the southern portion of the site is southeasterly. South of the site, in the area known to be more highly contaminated with coal-tar waste, the flow in the middle drift aquifer is generally eastward toward the buried bedrock valley. The exact direction and rate of movement through the middle drift aquifer through the area is not quantifiable and is, therefore, bracketed by the two interpretations. Flow through the middle drift aquifer beneath the northern portion of the site could not be determined with as much accuracy as flow in the other areas due to the loss of Well 3. Flow in the middle drift aquifer beneath the northern portion of the site, however, is hypothesized to be southerly or southeasterly.

The average rates of horizontal inflow and outflow through the middle drift aquifer (Q_{im} and Q_{om}, respectively) were computed for the winter period. The computation was based on the aquifer cross-section shown in Figure 2, the permeabilities for the middle drift aquifer discussed in Section III and the average piezometric gradients measured during the winter period shown in Figure 13. During the winter period, the average rate of inflow (Q_{im}) across piezometric contour A between the stream lines shown in Figure 13 was estimated to be 4,600 cfd (24 gpm) or 2.9 cfd per foot of width along piezometric contour A. The average rate of outflow (Q_{om}) between these two stream lines across piezometric contour B was estimated to be 2,600 cfd (14 gpm) or 2.5 cfd per foot during this same period. Thus, the inflow is of the same order of magnitude as the outflow with about one-half the inflow lost in leakage from the middle drift aquifer.

Figure 14 shows the piezometric levels across the study area on June 15, 1977. This information is presented because piezometric conditions were significantly different from those during the earlier portion of the study period. Also, there is additional information about the distribution in piezometric levels at the base of the lower drift on this date. Ground water levels rose in most observation wells during April and May, 1977 due to the precipitation that had been below normal during the previous portion of the study period.

The June piezometric gradient across the site is slightly greater than that measured during the winter. This is, in part, due to recharge. There is also evidence of an unknown pumping center drawing from the middle drift aquifer east of Well 12. Evidence of this pumping center is the significant decrease in piezometric level in the middle drift aquifer as measured at Well 12 and a corresponding decrease in piezometric level in the lower drift as measured by Piezometer P-2. However, it does not appear that the distribution in piezometric levels west of Well 11 was significantly affected by this pumping center, at least as of June 15, 1977.

The rate of inflow across piezometric contour C, between the two stream lines shown in Figure 14, was estimated to be 8,200 cfd (43 gpm) or 3.2 cfd per foot on June 15, 1977. The outflow across piezometric contour D, between the two stream lines, was found to be 4,100 cfs (21 gpm) or 2.7 cfd per foot. Again, it can be seen that the inflow and outflow are the same order of magnitude with approximately one-half the inflow lost to leakage to the lower drift.

Figure 14 also illustrates the piezometric levels at the base of the lower drift at the various monitoring wells and piezometers on June 15, 1977. Since these wells and piezometers are at the drift/bedrock contact, these data are representative of piezometric levels at the contact. Piezometric level contours have not been drawn for the contact because of the sparse data. However, levels at the drift/bedrock contact seem to follow the same pattern as levels in the middle drift aquifer, being highest to the west and south, and decreasing to the east.

If lateral ground water movement is occurring in the lower drift, it would be to the east. Lateral flow through the lower drift to the east, however, would seem to be blocked by the thick sequence of silts that make up the lower drift in the eastern portion of the study area. Likewise, lateral inflow to the lower drift through the study area is minimized by silts in the lower drift to the west. Thus, inflow to and outflow from the study area through the lower drift (Q_{il} and Q_{ol}, respectively) have been assumed to be negligible for purposes of the water balance under both interpretations. This leads to the conclusion that leakage from the middle drift aquifer must travel vertically through the lower drift to the underlying bedrock.

The differences between piezometric levels in the middle drift aquifer and the drift/bedrock contact along with the resistivity of the lower drift were used to calculate the rate of vertical leakage from the middle drift aquifer through the lower drift to the bedrock in the area between piezometric contours C and D and the two stream lines in Figure 14. The rate of vertical leakage was found to be 14,100 cfd (73 gpm) which represents approximately 36 inches per year of seepage over this area. Accounting for the difference between inflow and outflow through the middle drift aquifer, this would indicate a recharge from surface infiltration of 10,000 cfd or 26 inches per year. Since this seems higher than reasonable, the resistivities were re-examined.

Since the difference between lateral inflow and outflow in the middle drift aquifer for the winter and June periods ranged between 2,000 cfd and 4,100 cfd per foot with an average of 3,100 cfd, the difference between lateral inflow and outflow through the study area can be assumed to be quite constant throughout the year. With 3 inches per year as a reasonable long-term average surface infiltration rate over the area, the average leakage from the middle drift aquifer is approximately 4,300 cfd. When the surface infiltration rate of 3 inches per year is applied to the June, 1977 water balance, the leakage rate is estimated to be 5,300 cfs. Using this leakage rate and the observed differences in piezometric levels, a revised resistivity of 1.4×10^7 sec is calculated which is 2.7 times higher than the originally determined value. Since the estimate of resistivities of the lower drift could easily vary by this amount, this revised resistivity seems reasonable.

There are ways in which leakage rates from the middle drift aquifer through the lower drift could be higher for both the winter and June cases. From March, 1976 to February, 1977, there was little precipitation in the area and piezometric levels in the middle drift aquifer declined about 4.2 feet at a mean rate of 1.3×10^{-2} feet per day. This resulted in portions of the middle drift aquifer becoming unconfined during this period, a partial dewatering of this aquifer, and a corresponding loss from storage. In early summer of 1977, there was an increase in precipitation over the area, and it is possible that the infiltration rate during this early summer period was greater than 3 inches per year. Both the loss from storage and the higher than normal infiltration rate would increase the estimated amount of leakage. However, leakage rates in both instances are unquantifiable, and furthermore do not change the general picture of flow in the middle drift aquifer. Vertical leakage from the middle drift aquifer is about equal to the lateral flow leaving the area southeast of the site through this aquifer. Since lateral flow through the lower drift is negligible, this leakage must be continuing downward into the Platteville limestone formation. It is thus concluded that vertical leakage to the Platteville is an important ground water outflow route from the area south of the site.

HOW ACCURATE IS THIS & WHY?

The second interpretation of the available information assumes that the middle drift aquifer beneath the recharge area east of the site is quite permeable, contributes significant recharge to the study area and thus influences flow in the area. Consequently, the piezometric contours are concave. This deflects the flow lines to the southeast, indicating a much greater rate of seepage from the middle drift aquifer through the lower drift under this interpretation of the data.

Figure 15 shows the distribution in piezometric levels in the middle drift aquifer on February 21, 1977 for this second interpretation. Under these conditions, leakage rates from the middle drift aquifer would be on the order of five times greater than leakage rates under the first interpretation. Consequently, if this interpretation is accurate, ground water flow from the study area is dominated even more by leakage into the Platteville.

The results of the two interpretations lead to different pictures of ground water movement through the Platteville. The first interpretation indicates that the Platteville collects leakage from the middle drift aquifer rather uniformly over the study area, implying an extensive system of joints and fractures. The second interpretation indicates that the Platteville collects leakage from the middle drift aquifer almost exclusively under the axis of the piezometric contours. This implies that the Platteville is rather impermeable with ground water movement controlled by a few joints and fractures which are, nevertheless, capable of conducting large quantities of water.

During years of more normal precipitation, a new equilibrium will be established between lateral movement out of the study area through the middle drift aquifer and vertical seepage from the middle drift aquifer to the Platteville. This new equilibrium will depend upon the piezometric gradients in the middle drift aquifer across the study area and on the vertical gradients between the upper, middle and lower drift units. In reviewing the available piezometric data, the general piezometric gradient in the middle drift aquifer across the study area did not change significantly with the wide range in piezometric levels measured during the study period. Thus, it is hypothesized that lateral flow into and out of the study area through the middle drift aquifer will not change significantly under various precipitation patterns. The sparse data that are available also indicate that changes in piezometric levels at the base of the lower drift are generally similar to changes in piezometric levels in the middle drift. If this holds true in the long term, it will indicate that vertical seepage from the middle drift to the bedrock also should not change significantly with various precipitation patterns. If this is the case, it can be concluded that the lateral and vertical ground water movement rates obtained by the water balance approach are generally representative of conditions in the study area and the prime variables are the volume of water in storage in the upper drift and the piezometric levels in the Platteville limestone.

Available data indicate that the flow in the Platteville limestone is to the east, likely to the buried bedrock valley shown on Figure 7. Flow in the Platteville limestone formation is through fractures and fissures that have become solution channels, so even a rough estimate of rate and direction of movement is difficult to make. It is, however, logical that movement is to the bedrock valley, because that is the likely outlet developed during the pre-glacial period. Flow in the Platteville from the area southeast of the site was likely intercepted by pumping from wells that are uncased through the Platteville such as the Midco Register and Terry Excavating wells. That water in the Platteville which was intercepted by these wells is indicated by the high phenolic concentration in samples collected from these wells. Samples collected during this study, for example, indicate that phenolic concentrations in the Midco Register well were similar to phenolic concentrations measured at the drift/bedrock contact in the area of this well. During times that these uncased wells are not being pumped, they provide a flow path for water to move from the Platteville down into the St. Peter aquifer. The existing data permit a range of interpretations about the configuration of flow paths in the Platteville. Furthermore, the nature of flow through the Platteville makes it difficult to monitor the quality of water in the Platteville since the monitoring wells must intercept the fractures that are carrying this water. Predicting the rate of movement through the Platteville is thus one of the most difficult factors to quantify. This is unfortunate because of the importance of the Platteville as a potential means of carrying ground water with elevated phenolics and polynuclear aromatic hydrocarbons away from the study area.

There is no data on ground water movement through the Platteville limestone between Well 12 and the buried bedrock valley. It can be assumed, however, that the solution channels in the Platteville that carry ground water seepage from the glacial drift beneath the study area continue to carry flow all the way to the buried bedrock valley. The alternative is that there may be fewer cracks and fissures in the Platteville between Well 12 and the buried bedrock valley. Under this alternative, water in the Platteville would reenter the glacial drift and continue to the buried bedrock valley through the drift. Due to the large quantity of flow from the drift to the Platteville and due to the likely geologic history of solution channels in the Platteville, this alternative seems unlikely and was not investigated further.

Several assumptions were used to estimate flow time through the Platteville to the buried bedrock valley. The bedrock valley with missing Glenwood shale was assumed to be a well with a radius of 500 feet. The St. Peter was considered to be confined between the site and the bedrock valley. The equilibrium piezometric level at the buried bedrock valley was estimated by computing the discharge rate through the Platteville that was equal to the recharge rate to the St. Peter through the buried bedrock valley.

The buried bedrock valley was estimated to recharge 80,000 cfd in the winter and 160,000 cfd in the summer to the St. Peter. Given this range in recharge rates to the St. Peter through the buried valley and the distance from the buried valley to the area near Well 13, it would take an estimated

20 to 25 years for flow through the Platteville to reach the bedrock valley during summer conditions and an estimated 40 to 50 years during winter conditions. These flow times are based on the gross area of the Platteville and must be multiplied by porosity to obtain a more reasonable estimate of actual flow time. Due to the unknown porosity of the Platteville, this could not be done, but the actual flow times would be less than the above times. Thus, it is possible that water from the Well 13 area is already reaching the buried bedrock valley and is migrating to the St. Peter.

Ground Water Quality

The ground water quality data collected from the various monitoring wells as well as the glacial drift piezometric levels were used to help define the quality of ground water in the glacial drift. The ground water quality data was used to plot phenolic concentration contours corresponding to the two interpretations of ground water movement through the middle drift aquifer. The contours for May-June, 1977 by the first interpretation are illustrated in Figure 16. The distribution of phenolics in samples from the soil borings were also used as an aid in constructing these contours. Where ground monitoring wells were nested, the highest concentration measured in the nested wells was used to construct the contours. Thus, these contours reflect a maximum phenolic concentration measured in the glacial drift ground water column.

The ground water quality data indicate that phenolic concentrations measured from samples collected from each well show a high degree of variation. For example, a sample collected on April 1, 1976 from Well 9 had a phenolic concentration of 3.00 milligrams per liter while samples collected during May and June, 1977 had phenolic concentrations of .60 milligrams per liter. This may reflect a variation in the spacial distribution of phenolics in the ground water system, different pumping rates and pumping times prior to sample collection or changing ground water quality.

The contours in Figure 16 show that the area of highest phenolic concentration seems to be located in the wetland area between Highway 7 and

Lake Street that received surface runoff from the site. Phenolic concentrations as high as 50 milligrams per liter and total polynuclear aromatic hydrocarbon concentrations as high as 3,400 milligrams per liter were measured from Well 13 with a well point located at the base of the middle drift aquifer, 50 feet below the ground surface. Water samples collected from this point have a brown color with a characteristic coal-tar odor. Water samples from Well 9 approximately 700 feet to the east of Well 13 indicate phenolic concentrations approximately two orders of magnitude lower and concentrations of total extractable organics approximately three orders of magnitude lower than concentrations at Well 13. Well 9 is outside the wetland area that received the surface runoff from the site. The absence of polynuclear aromatic hydrocarbons in samples from Well 9 could be explained by the fact the screen for Well 9 is placed in the upper portion of the middle drift aquifer while the screen for Well 13 is placed at the base of the aquifer. Polynuclear aromatic hydrocarbons are known to have specific gravities greater than 1.0 so this portion of the coal-tar waste could be expected to move downward due to its specific gravity and due to the downward component of flow. The contours representing phenolic concentrations of 100 micrograms per liter and 10 micrograms per liter stretch out in the direction of decreasing piezometric levels to the east. Thus, the data indicate that the phenolics are being carried with the ground water flow in the middle drift aquifer to the east.

Ground water quality data collected from nested Wells 11 and 17 indicate that phenolic concentrations in the lower glacial drift are approximately one order of magnitude higher than phenolic concentrations in the middle drift stratum at the same location in the eastern portion of the study area. This is additional evidence that the vertical component of flow from the middle drift aquifer is substantial. The fact that the lower glacial drift in the eastern portion of the study area has phenolic concentrations in the range of .20 to .30 milligrams per liter is a significant finding of the study since it shows that vertical leakage to the Platteville limestone likely also has elevated phenolic concentrations. This is the likely reason that the Midco Register well and other wells in the area that are uncased in the Platteville, supply water with elevated phenolic concentrations. Available information shows that Well 17, at the base of the lower drift, has a concentration of polynuclear aromatic hydrocarbons equal to 1.7 milligrams per liter. This indicates that polynuclear aromatic hydrocarbons are moving away from the contaminated area around Well 13 and are also likely reaching the Platteville limestone. The specific polynuclear aromatic hydrocarbons found in samples from Well 17 were not identified in this study.

Available laboratory data indicate that the specific gravity of the settleable material in water samples from Well 13 is on the order of 1.02. Thus, the material is denser than water, and this represents an additional mechanism distributing it to a depth of 50 feet and to the base of the lower drift near Well 17.

The existing monitoring well network was not adequate to define the location of the phenolic contours shown as dashed in Figure 16. These include the northeastern and eastern portions of the 10 microgram per liter and the 100 microgram per liter contours. The limits of the contaminated area to the south, to the west and to the northwest are defined by wells that monitor the middle drift aquifer, but show undetectable or very low phenolic concentrations.

The distribution of phenolic concentration contours that correspond to the second interpretation of ground water movement through the middle drift aquifer are shown in Figure 17. This distribution is different from the distribution shown in Figure 16 in that the axis of the contours is deflected to the south approximately 25 degrees. The existing phenolic concentration data would seem to support the first interpretation; however, dispersion and the effect of historical pumping from the Midco Register well could help explain the reasons for the measured phenolic concentrations directly east of the wetland area between Highway 7 and Lake Street under the second interpretation.

The only data available on the quality of water in the Platteville are from industrial wells that are uncased and, therefore, presumably draw water from this formation. The Midco Register well presents the best example. Between late 1973 and early 1974, phenolic concentrations (MBTH Method) varied from 1.0 to 1.4 milligrams per liter in samples collected from this well. Between April, 1976 and May, 1977, phenolic concentrations (4-amino-antipyrine colormetric method) varied between .170 and .390 milligrams per liter. Data from Well 17, placed near the drift/bedrock contact close to the Midco Register well, indicate phenolic concentrations between .032 mg/1 and .28 mg/1 (4-aminoantipyrine colormetric method) and equal to .340 mg/1 (MBTH Method). The concentration of polynuclear aromatic hydrocarbons in samples from Well 17 was 1.7 mg/1. Thus, it can be concluded with reasonable certainty that coal-tar waste as measured by phenolics and polynuclear aromatic hydrocarbons are reaching the Platteville and moving with the ground water through the Platteville.

EXISTING BEDROCK CONDITIONS

As discussed in the subsection on glacial drift ground water movement, seepage to the Platteville limestone is a major outflow route from the glacial drift. For this reason, flow in the Platteville was discussed in the subsection on glacial drift ground water movement. The focus of this subsection is on ground water movement, both laterally and vertically, in the bedrock units below the Platteville. The distribution of piezometric levels in the St. Peter and Prairie du Chien-Jordan aquifers were determined by the multi-aquifer model of Hetizman and Strack discussed in Section III. The distribution of piezometric levels during winter and summer conditions were calculated for both aquifers. In addition, available information was used to assess ground water movement in the Mt. Simon-Hinckley aquifer. Vertical leakage rates between the Platteville and St. Peter, between the St. Peter and the Prairie du Chien-Jordan, and between the Jordan and Mt. Simon-Hinckley were estimated on the basis of permeability data presented in Section III and measured or assumed piezometric levels.

Ground Water Movement

Leakage through the Glenwood shale represents one of the possible inflow routes to the underlying bedrock aquifers from the glacial drift and Platteville limestone. Using an average difference in piezometric levels between the lower drift and St. Peter of 18 feet, and the estimated vertical permeability of the Glenwood of 10^{-8} cm/sec, results in an estimated rate of leakage through the Glenwood aquitard of 0.061 feet per year. This leakage rate must be divided by the porosity of the Glenwood to estimate the actual velocity of water moving through the Glenwood. If the porosity is assumed to be 10%, the average velocity through the Glenwood is .61 feet per year. Since the Glenwood is estimated to be an average of 3 feet thick over the study area, water will take an average of 5 years to travel through this aquitard under these assumptions. As discussed in Section III, however, the permeability of the Glenwood is controlled by the degree of fracturing that is present and by the degree to which these fractures have become plugged with fine soils during the thousands of years that leakage has been occurring. Without the effect of plugging with fine soils, the rate of water movement through the fractures would be expected to be very rapid due to the vertical piezometric gradient across the Glenwood. Thus, the predicted flow time through the Glenwood of 5 years is really not very meaningful. More meaningful is the fact that analyses of samples from Well 14 (a St. Peter well directly beneath the area of coal-tar waste in the drift) exhibits phenolic concentrations similar (undetectable by 4-aminoantipyrene colormetric method and less than 10 micrograms per liter by the MBTH Method) to those measured in the City St. Peter wells at the 29th Street and Idaho Avenue well field approximately 1 mile to the north. If the Glenwood was fractured, it seems logical that the phenolic concentrations would be higher beneath the area of coal-tar waste in the drift.

The distribution of piezometric levels in the St. Peter aquifer during the winter months is shown in Figure 18. As shown, the general direction of ground water flow is to the east; however, several geologic features and wells affect this general pattern. Most striking is the effect of the buried bedrock valley in the southeastern portion of the study area. As discussed in Section III, this buried bedrock valley cuts through the Glenwood, thereby connecting the glacial drift/Platteville directly to the St. Peter aquifer. The resulting flow into the St. Peter through this bedrock valley creates a prominent recharge zone which blocks the general eastward flow in the St. Peter west of the buried bedrock valley. This creates an area of increased piezometric levels and reduced piezometric gradients in the St. Peter formation in the southwestern portion of Figure 18 south of Highway 7.

The effects of three St. Peter wells can also be noted on the general winter flow in the St. Peter in the study area. These are the wells originally drilled for Terry Excavating Company, Robinson Rubber Company (now Midco Register) and the City of St. Louis Park at their 29th Street and Idaho Avenue well field. As discussed in Section III, logs for these wells indicate the wells are finished in the St. Peter but are likely only cased to the first bedrock contact. The high phenolic concentrations in water from the Terry Excavating and Midco Register wells is evidence that these wells are directly connected to the glacial drift or Platteville. During periods when these wells are not pumped, their construction allows water from the Platteville to enter the St. Peter formation, thus creating recharge mounds in the St. Peter in the vicinity of these two wells. As shown in Figure 18, water recharging through the Midco Register well will flow south and northeast, while water recharging through the Terry Excavating well will only flow northeast. The third well influencing flow in the St. Peter is St. Louis Park Well 3, located at the 29th Street and Idaho Avenue well field. At one time, there were three St. Peter wells (City Wells 1, 2 and 3) in use at this well field; however, only City Well 3 is now used to any great extent. For modeling purposes, the three wells were considered as a single well. Figure 18 indicates that the winter piezometric gradients are such that the St. Peter wells at the 29th Street and Idaho Avenue well field will intercept flow from the west as well as a portion of the recharge supplied through the Terry Excavating and Midco Register wells. According to the piezometric levels generated by the model and the assumed permeability and porosity of the St. Peter formation, flow from the Terry Excavating and Midco Register wells will take on the order of $\boxed{150}$ years to reach the 29th Street and Idaho Avenue well field through the St. Peter along the shortest stream line under the computed winter distribution of piezometric levels. This estimated flow time is based on the Terry Excavating and Midco Register wells not being pumped. Periodic pumping of these two wells greatly complicates the analysis since a portion or all of the water recharged through the wells will be recaptured during pumping periods. Under the winter conditions, it is estimated that recharge from these two wells will eventually comprise approximately 19% of the total inflow to the St. Peter wells at the 29th Street and Idaho Avenue well field. Stream lines for the portion of the recharge through the Midco Register and Terry Excavating wells that can reach the City St. Peter wells are shown on Figure 18.

The piezometric distribution in the St. Peter aquifer during the summer months is shown in Figure 19. This distribution is similar to the winter case with slight modifications due to increased pumping from the St. Peter wells at the 29th Street and Idaho Avenue well field during the summer and a greater rate of recharge through the Terry Excavating and Midco Register wells. This increased rate of recharge is due to a general lowering of the piezometric levels in the St. Peter in the summer caused by increased summer withdrawals from all aquifers. Under summer conditions, ground water movement is complex through the St. Peter beneath the southern portion of the site and the area south of the site and north of Lake Street. As shown in Figure 19, flow from a portion of the area moves to the south and flow from the remaining portion moves to the northeast. Because of the greater summer pumping rate, the St. Peter well at the 29th Street and Idaho Avenue well field will intercept a larger portion of the recharge from the Terry Excavating and Midco Register wells than under winter conditions. Under the assumed summer conditions, recharge to the St. Peter through the Terry Excavating and Midco Register wells would take on the order of 30 years to reach the City St. Peter wells along the most direct stream line, again assuming that the Terry Excavating and Midco wells are not pumped. The stream lines defining water movement from these recharge wells to the City St. Peter well are shown in Figure 19. Under these conditions, recharge from these two wells would eventually contribute an estimated 60% of the water pumped from the City St. Peter well during the winter.

Under both summer and winter conditions, recharge from the glacial drift and/or Platteville to the St. Peter through the buried bedrock valley will not reach the St. Peter wells at the 29th Street and Idaho Avenue well field, but instead will flow easterly out of the area. It must be cautioned, however, that the exact configuration of the buried bedrock valley is unknown. If the buried valley through the Glenwood extends further north, City St. Peter wells at the 29th Street and Idaho Avenue field could intercept flow from the valley. In addition, recharge through this expanded buried valley would shift the piezometric distribution so as to cause the St. Peter wells at the 29th Street and Idaho Avenue well field to intercept more or even all of the recharge from the Midco Register and Terry Excavating wells.

Vertical leakage from the St. Peter to the underlying Prairie du Chien-Jordan is controlled by the siltstone stratum at the base of the St. Peter. Using the thickness and assumed permeability of this stratum discussed in Section III, it was found that the resultant leakage into the Prairie du Chien-Jordan aquifer was too great and the known boundary conditions could not be met. The permeability of the basal drift aquitard was, therefore, reduced from 2×10^{-6} cm/sec to $.4 \times 10^{-6}$ cm/sec (1.1×10^{-3} ft/day) to match the known boundary conditions. Using this revised permeability, the thickness of the aquitard and an assumed difference in piezometric levels between the St. Peter and Prairie du Chien-Jordan of 33 feet, the estimated vertical seepage from the St. Peter to the Prairie du Chien-Jordan is .19 feet per year. Dividing this vertical seepage rate by the assumed porosity of 20% results in an estimated rate of water movement through the siltstone stratum of 1 foot per year. Thus, it would take an estimated 55 years for water to travel through the basal siltstone stratum of the St. Peter formation. This flow time is considered to be a much more reliable estimate than the estimate for the Glenwood due to the expected absence of fractures in the basal siltstone stratum of the St. Peter.

The distribution of piezometric levels in the Prairie du Chien-Jordan aquifer during the winter months is shown in Figure 20. As shown, ground water movement in the Paririe du Chien-Jordan is dominated by flow to the east. Wells considered in the model were the Prairie du Chien-Jordan wells at the City's 29th Street and Idaho Avenue well field (City Wells 10 and 15), City Wells 5 and 6, Flame Industries, S & K Products, Minnesota Rubber, Methodist Hospital (summer case), Sterilized Diaper Service, the Mt. Simon-Hinckley well located on the site and nine wells to the west of the study area belonging to several municipalities. The effects of only the Minnesota Rubber well, the Mt. Simon-Hinckley well on the site and the Prairie du Chien-Jordan wells at the 29th Street and Idaho Avenue well field are visible on the computed distribution of piezometric levels. The Minnesota Rubber well and the City wells intercept flow from the west, but do not alter the general ground water movement sufficiently to affect flow in the study area. The drawdown cone at the Mt. Simon-Hinckley well on the site is formed because the uncased portion of this well permits discharge from the Prairie du Chien-Jordan to the Mt. Simon-Hinckley aquifer causing this drawdown. Times of travel are not as predictable in the Prairie du Chien-Jordan as they are in the St. Peter due to the fractured nature of certain members of the Prairie du Chien. The assumed permeability of the entire group, however, can be used along with the piezometric levels and an assumed porosity to estimate times of travel. For example, it would take water on the order of 50 years to travel through the Prairie du Chien-Jordan from beneath the site to the Minnesota Rubber well under assumed winter conditions. However, this computed flow time was based on treating the Prairie du Chien and Jordan aquifers as a single hydrologic unit with a porosity equal to the Jordan. Because of fractures, joints and solution channels in the Prairie du Chien, it is possible that the water from beneath the site could reach the Minnesota Rubber well in a shorter period of time.

The distribution of piezometric levels in the Prairie du Chien-Jordan aquifer during the summer is shown in Figure 21. Again, a gradient to the east dominates the flow, but because of increased pumping the gradients are slightly different than the winter case. Under summer conditions, seven wells noticeably affect the distribution of piezometric levels in the Prairie du Chien-Jordan. These are Hopkins Well 3 to the southwest, St. Louis Park Well 5 to the west, St. Louis Park Wells 10 and 15 to the north, the Mt. Simon-Hinckley well on the site, the Minnesota Rubber well to the east and the Methodist Hospital well to the southeast. Under assumed summer conditions, it would take an estimated 30 years for water to reach the Minnesota Rubber well through the Prairie du Chien aquifer from beneath the site using the same permeability and porosity assumptions as used in the winter case.

The period of time required for vertical seepage from the Jordan aquifer to reach the Mt. Simon aquifer was estimated by assuming that only the Eau Claire formation separates the two aquifers. Since the St. Lawrence and other units are also located between the Jordan and the Mt. Simon, this assumption will result in a maximum seepage rate and a minimum flow time.

Using an assumed vertical permeability through the Eau Claire of 10^{-10} cm/sec (Norvitch, 1973) and a thickness of 87 feet, the rate of seepage was calculated to be 2.6×10^{-4} feet per year. With an estimated porosity of 10%, the time of travel would be 34,000 years. To estimate a more reasonable flow time, flow through all units between the Jordan and Mt. Simon would have to be considered. However, since no permeability data is available for the St. Lawrence, this was not done. Thus, it is concluded that the Mt. Simon-Hinckley aquifer is isolated from the Prairie du Chien-Jordan except for recharge from wells that provide direct flow paths between the upper formations and the Mt. Simon-Hinckley.

No additional Mt. Simon-Hinckley wells were found in the study area other than five wells identified by Sunde (1974). These Mt. Simon-Hinckley wells are the well on the site of the former coal-tar distillation and wood-preserving facility; the well originally placed for the railroad; and St. Louis Park Wells 11, 12 and 13. City Well 11 is located at the 29th Street and Idaho Avenue well field, City Well 13 is located along Minnehaha Creek near T.H. 100 south of the study area, and City Well 13 is located northeast of Well 11 along Cedar Lake Road. Only the three City wells have been pumped in recent years. Together, these three wells create a piezometric low in the Mt. Simon-Hinckley aquifer for the western part of the metropolitan area. Of the three wells pumping from the Mt. Simon-Hinckley aquifer, St. Louis Park Well 11 causes the greatest drawdown. Recharge to the Mt. Simon-Hinckley from overlying aquifers through the site well and the railroad well will flow to the City wells with almost all of the flow to Well 11. Using the estimated permeabilities, thickness and porosity of the Mt. Simon-Hinckley presented in Section III and the estimated piezometric gradients from Norvitch (1973), the minimum time for flow to travel from the site well to City Well 11 is estimated to be on the order of 4 years under summer and winter conditions.

Ground Water Quality

Changes to the natural quality of ground water in the various bedrock aquifers due to the coal-tar wastes identified in the glacial drift and Platteville limestone are obviously controlled by movement of ground water between the glacial drift/Platteville system and the bedrock aquifers. As discussed in the preceding paragraphs, movement between these formations can occur in basically two ways. The first route is by seepage through the aquitards that separate the bedrock aquifers. As shown in the preceding analysis, velocity of ground water seeping through aquitards is slow, being on the order of 1 foot per year through the siltstone stratum at the base of the St. Peter, and .001 foot per year through the various aquitards separating the Jordan sandstone and the Mt. Simon-Hinckley aquifer. Calculated flow times through these aquitards are on the order of 55 years through the siltstone stratum of the St. Peter and at least 34,000 years through the various aquitards between the Jordan and the Mt. Simon-Hinckley. Thus, under the assumed permeabilities and gradients it seems unlikely that the coal-tar derivatives that are known to be present at the base of the glacial drift and in the Platteville limestone could have traveled to the Prairie du Chien-Jordan through the siltstone stratum of the St. Peter, or to the Mt. Simon-Hinckley through the Eau Claire. If the assumed permeabilities are increased by an order of magnitude, it still seems unlikely that coal-tar derivatives could be reaching the underlying bedrock aquifers through these aquitards.

As discussed previously, flow through the Glenwood shale is much more difficult to predict. Evidence that very little seepage is occurring is shown by the very low phenolic concentrations in the St. Peter beneath the highly contaminated areas in the drift and high piezometric gradient across the Glenwood. With an assumed permeability of 10^{-8} cm/sec and a porosity of 10%, a flow time as short as 5 years can be computed. Qualitatively, it can be concluded that the amount of water seeping through the Glenwood is likely very small in comparison to lateral flow in the St. Peter or Platteville; however, the velocity of downward movement through the Glenwood is probably relatively fast in relation to movement through the other aquitards.

The second possible flow path from the glacial drift to the underlying bedrock aquifers is through the various uncased bedrock wells that have been constructed in the area. These include St. Peter wells cased only to the first bedrock contact that provide a flow route between the glacial drift/Platteville system and the St. Peter. Examples include the Terry

Excavating and Midco Register wells. The Terry Excavating and Midco Register wells are cased only to the uppermost bedrock contact and the open hole extends into the St. Peter sandstone. Undoubtedly, there are other similar wells in the area, but these two wells are the only ones that could be identified using the available data. Other wells such as the St. Peter well on the site are cased to the Platteville and extend through the Platteville into the Glenwood or possibly to the very top of the St. Peter. The available log for the site St. Peter well, however, indicates that the open hole does not extend into the St. Peter, so only a small area is available for recharge to the St. Peter. Thus, the effects of wells such as this were not considered in the analysis of ground water movement between aquifers.

Other uncased wells seem to connect the upper bedrock aquifers to the Mt. Simon-Hinckley. The Mt. Simon-Hinckley well identified by Sunde (1974), for example, originally drilled for the Milwaukee Railroad, is reportedly cased only to the St. Peter and thus forms a flow path between the St. Peter-Prairie du Chien-Jordan aquifers and the underlying Hinckley formation. Logically, vertical flow through this well would be from the St. Peter to the Mt. Simon-Hinckley and from the Jordan to the Mt. Simon-Hinckley due to the progressively lower piezometric levels in each of these three aquifers. If this well was constructed this way, however, the upper St. Peter has likely eroded into the open hole. The Mt. Simon-Hinckley well on the site is reportedly cased into the Prairie du Chien, thus permitting flow from the Prairie du Chien-Jordan to the Mt. Simon-Hinckley.

An inventory of available data was made to find wells in the area that could provide a direct connection between the glacial drift/Platteville or the upper St. Peter and the Prairie du Chien-Jordan aquifer. The Prairie du Chien-Jordan well placed for the Strom Block Company is cased into the siltstone aquitard in the St. Peter formation and the Midco Register well is only drilled to the upper reaches of the St. Peter formation. The Jordan wells drilled for the Sterilized Diaper Service, Minnesota Rubber, and Flame Industries are all shown to be cased into the Prairie du Chien formation. Thus, the review of available information did not show any wells that would likely provide a connection between the glacial drift/Platteville or the upper St. Peter and the Prairie du Chien-Jordan. If the concentrations of phenolics that have been measured in the various Prairie du Chien-Jordan wells in the area are to be attributed to coal-tar wastes in the glacial drift/Platteville, it seems there must be an unidentified well or wells that provide a pathway between the drift, Platteville or upper St. Peter and the Prairie du Chien-Jordan. There are undoubtedly other wells in and around the area of contamination in the glacial drift that have not been located. An example is the well originally drilled for Terry Excavating that was learned of through a chance discussion with a water well contractor.

★ Question this?

Another explanation that has been offered for the elevated phenolic concentrations in the Prairie du Chien-Jordan aquifer is the induced recharge that occurs during pumping from the Prairie du Chien-Jordan well. This additional drawdown in the Prairie du Chien-Jordan will result in increased vertical recharge through the siltstone aquitard in the St. Peter, thus increasing the rate of recharge. However, computations indicate that this is not a satisfactory explanation for the elevated phenolic concentrations measured in the Jordan wells during late 1973 and early 1974.

In summary, the available information seems sufficient to explain the very low concentrations of phenolics in the St. Peter beneath the area south and southeast of the site. This could be attributed to leakage through the Glenwood or to recharge from uncased wells. Available information does not seem sufficient, however, to explain the phenolic concentrations measured in the Prairie du Chien-Jordan formation at Flame Industries, Minnesota Rubber and other Jordan wells in the study area. If these phenolic concentrations are to be attributed to the site, the only explanation seems to be that one or more unknown wells in the study area connect the glacial drift, Platteville or upper St. Peter with the Prairie du Chien-Jordan. The computed piezometric gradients and flow times seem sufficient to explain the reasons for the trace phenolic concentrations measured in the City Mt. Simon-Hinckley wells, especially if a spill of coal-tar material did travel down the Mt. Simon-Hinckley well on the site. The available information, however, is not sufficient to explain the reasons for the measured phenolic concentrations in the municipal St. Peter and Prairie du Chien-Jordan wells located at 29th Street and Idaho Avenue well field or at other municipal well fields in the area.

★ what about other phenolic measures further north

In the case of the City St. Peter wells at the 29th Street and Idaho Avenue well field, the gradient is sufficient to move recharge to the wells from the Terry Excavating and Midco Register wells; however, the time between construction of the Terry Excavating and Midco Register wells (or the time since pumping of the Midco Register well stopped) and the detection of phenolic concentrations in samples from the City wells is too short for the water in the St. Peter formation to have traveled between these two points based on the computed winter and summer travel times.

As discussed in the subsection on glacial drift ground water movement, the gradient in the Platteville limestone formation seems to follow the gradient in the glacial drift which is east from the contaminated area of the glacial drift. Thus, movement through the Platteville limestone and recharge through the Glenwood formation in the area of the City wells would also not seem to be a satisfactory explanation for the elevated phenolic concentrations measured at the City wells. However, it should be pointed out that a review of the logs for City Wells 1, 2 and 3 indicate that these wells are likely cased only to the upper portion of the Platteville limestone. If these wells pump water from the Platteville, it is possible that the gradient in the Platteville more closely resembles the gradient in the St. Peter formation which has been shown to be toward the City wells from the site. The sketchy data that is available on the piezometric levels in the Platteville limestone between the site and the 29th Street and Idaho Avenue well field could be interpreted so as to rationalize that flow is possible between the site and the well field. Although the data are not at all adequate to determine whether this hypothesis is correct, flow through the Platteville limestone from the area of the site to the well field would seem to be only a remotely possible mechanism for the movement of coal-tar wastes to that well field.

In the case of the Prairie du Chien-Jordan wells, the computed gradients show that water cannot be transmitted from the general area of the site to the City well field through this aquifer.

SECTION V

PREDICTED FUTURE GROUND WATER CONDITIONS

SECTION V

PREDICTED FUTURE GROUND WATER CONDITIONS

Using the information from the preceding section, it is possible to generally predict the future spread of coal-tar derivatives through the middle drift aquifer. Future ground water movement in the bedrock aquifers in general should not change significantly in the foreseeable future except for a continuation in the general lowering of piezometric levels that has been occurring for the past 30 years. Since the data and the computations carried out for this study do not satisfactorily explain the reasons for the detectable phenolic concentrations in samples from the municipal St. Peter and Prairie du Chien wells, it is not possible to project any changes in this condition.

Predicted future glacial drift and bedrock conditions are described separately in the two subsections of this section.

FUTURE GLACIAL DRIFT AND PLATTEVILLE CONDITIONS

The existing winter piezometric contours in the middle drift aquifer shown in Figure 13, along with the assumed range in middle drift permeabilities were used to predict the rate of ground water movement through the middle drift aquifer. This information was then used to estimate the rate of movement of the various phenolic concentration contours shown in Figure 16, neglecting the effects of dispersion and diffusion. Existing piezometric data indicate that the general winter piezometric gradient across the study area is approximately 1 foot vertical in 1,200 feet horizontal. Using this gradient, along with a range in middle drift aquifer permeabilities of 1×10^{-2} cm/sec to 5×10^{-2} cm/sec, and a porosity of 30%, results in average velocities through the pore spaces of the middle drift in the range of 30 feet per year to 150 feet per year. At these velocities, it would have taken on the order of 20 to 100 years for the 10 microgram per liter phenolic concentration contour to expand from the wetland area between Lake Street and Highway 7 to the assumed present eastern limit shown in Figure 16. This seems a reasonable range in travel time, especially considering that the

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data supports permeabilities in the lower end of the above range in the eastern portion of the study area. Under these assumptions, the 1,000 micrograms per liter and the 100 micrograms per liter phenolic concentration contours could be expected to move eastward at a rate on the order of 30 to 150 feet per year with more weight given to rates near the lower end of this range.

The stratigraphy and permeability of the middle drift aquifer east of the study area is unknown. Soils in the middle drift aquifer appear to become less permeable to the east, so it could be anticipated that the rate of movement of the 10 microgram per liter contour would be at a rate at the lower end or below the range of velocities found within the study area. Without additional information, however, nothing more can be said about the rate of movement of the 10 microgram per liter contour through the middle drift aquifer east of Well 17. It can be concluded that phenolic concentrations in the middle drift aquifer outside of the area of visible coal-tar waste near Well 13 are not at a steady state condition. The contours will, therefore, continue to expand.

Soil data collected from the upper drift in and around the wetland areas south of the site indicate that phenolics are present at concentrations two to three orders of magnitude above the concentrations measured at the base of the middle drift aquifer in this area. If phenolics are taken as a measure of the "leachable" fraction of the coal-tar waste, this indicates that the quality of ground water at the base of the middle drift aquifer may also not be at a steady state condition and that increased concentrations of phenolics and/or polynuclear aromatic hydrocarbons may occur at the base of the drift. To what extent this will occur will depend on the comparison between hydrocarbon loadings entering the middle drift aquifer from the upper coal-tar waste deposits and the hydrocarbon loadings leaving the contaminated middle drift area laterally and vertically to the Platteville.

Due to the likelihood that the concentrations of coal-tar waste to and from the bulb of waste identified in the middle drift aquifer have not reached a steady state condition, it is reasonable to assume that the concentration of coal-tar waste reaching the Platteville has also not reached a steady state condition and will continue to increase in the future. The data, however, are not sufficient to quantitatively predict even the magnitude of the future increase. It can be reasoned, however, that it will be a small but steady increase over the years since the ground water is moving so slowly through the glacial drift. No reason was found for a decrease in the concentration of coal-tar waste reaching the Platteville or moving laterally through the middle drift aquifer.

BEDROCK CONDITIONS

The computed flow times and velocities for water to move from probable sources of recharge to various water supply wells are summarized in the following table.

			Velocity (ft/yr)			Flow Time (yrs)		
Unit	From	To	V_{summer}	V_{winter}	$V_{avg.}$	T_{summer}	T_{winter}	$T_{avg.}$
St. Peter	Terry Excavating Well	City Well 3	125	30	77	32	153	56
Prairie du Chien-Jordan	Site	Minnesota Rubber Co.	144	86	115	29	48	36
Mt. Simon-Hinckley	Site Well	City Well 11	831	892	862	4.3	4.0	4.1

SUMMARY OF LATERAL GROUND WATER MOVEMENT

Average velocities from the Terry Excavating and Midco Register wells to the City St. Peter wells at the 29th Street and Idaho Avenue well field are on the order of 30 to 125 feet per year depending on the stream line. Average velocities through the Mt. Simon-Hinckley between the site Mt. Simon-Hinckley well and the Mt. Simon-Hinckley well at the City's 29th Street and Idaho Avenue well field are 6 to 30 times faster than through the St. Peter. Since the flow time between the site Mt. Simon-Hinckley well and the 29th Street and Idaho Avenue well field is on the order of 4 years, the quality of water in the Mt. Simon-Hinckley, at least as it is affected by coal-tar wastes from the site, could be reasonably expected to be in a steady state condition.

Since the Terry Excavating and Midco Register wells were both installed in 1953, there has been the possibility of recharge to the St. Peter through these wells for about 25 years. Until recently, the Midco Register well has been heavily pumped and any recharge during nonpumping periods would logically have been recovered. In any event, the average flow time to reach the City St. Peter wells from the Terry Excavating well is on the order of 50 years which is about twice as long as the Terry well has been in place. The conclusion is thus reached that recharge through the Terry Excavating well cannot be the reason for the detectable phenolic concentrations in samples from the City St. Peter wells. Although the precision of the calculations may not warrant this conclusion, there is certainly no reason for the quality of water in the St. Peter to be at a steady state condition at the municipal well fields, with respect to wastes contributed by the coal-tar distillation and wood preserving facility.

If the Terry Excavating and Midco Register wells are grouted, water recharging to St. Peter sandstone through the buried bedrock valley will flow to the St. Peter wells at the City's 29th Street and Idaho Avenue well field. The distribution in piezometric levels for this case are shown in Figure 22. It would, of course, take a considerable number of years for the flow of water to move from the buried bedrock valley to the City wells, but nevertheless, a portion of the recharge to the buried bedrock valley will, in turn, recharge the City St. Peter wells after the Terry Excavating and Midco Register wells are abandoned. This leads to the conclusion that the City St. Peter wells should also be abandoned because of their influence on the movement of contamination reaching the St. Peter through the bedrock valley.

S E C T I O N V I

CORRECTIVE MEASURES

SECTION VI
CORRECTIVE MEASURES

The analyses carried out in the preceding two sections have shown that the glacial drift soils and ground water systems in the wetland area south of the site are contaminated to depths as great as 50 feet with coal-tar wastes containing phenolics and polynuclear aromatic hydrocarbons. Ground water movement in the glacial drift from this area is about equally split between lateral movement to the southeast and vertical movement to the Platteville limestone. The data show that phenolics and polynuclear aromatic hydrocarbons are moving from the most severely contaminated areas of the drift. Concentrations are approximately two orders of magnitude smaller 1,000 feet downgradient. The phenolics and polynuclear aromatic hydrocarbons have moved to the base of the glacial drift and are also likely moving away from the area through the Platteville. The likely rates at which these materials are moving are more predictable in the drift than through the Platteville due to the unknown permeability and porosity of the solution channels in the Platteville beneath the study area. It is hypothesized, however, that the direction of movement through the Platteville limestone is southeasterly toward a bedrock valley cut through the Glenwood into the St. Peter. Once the organic materials reach the buried bedrock valley, they can move vertically into the underlying St. Peter sandstone and from there easterly toward a second bedrock valley or to wells that draw from the St. Peter.

The results of the analyses carried out in this study suggest that the coal-tar waste in the glacial drift represents a potential threat to the underlying bedrock ground water aquifers for the following reasons:

a. A number of wells in the area are uncased through two or more bedrock aquifers, thus providing potential pathways for ground water movement between the upper units, such as the drift/Platteville, and the lower aquifers, such as the St. Peter and the Mt. Simon-Hinckley.

b. Downgradient of the bulb of contaminated ground water in the glacial drift there is evidence of a buried bedrock valley that will provide or is providing another connection between the glacial drift/Platteville ground water system and the St. Peter.

c. Existing industrial wells immediately downgradient of the contamination are slowly being abandoned for one reason or another. These wells, especially wells that are uncased through the Platteville, may have acted, at least partially, as barriers to ground water movement through the drift/ Platteville system. As these existing barrier wells are phased out and new barriers are established further to the east and to the south, the potential for the spread of organics from the contaminated area in the glacial drift is increased.

Thus, a major recommendation of this report is that the movement of identified coal-tar wastes in the middle drift aquifer and Platteville be controlled.

The purpose of this section of the report is to examine corrective measures for containing the spread of the coal-tar derivatives. The first measure examined is gradient control. Under this technique, a system of pumpout wells placed in the middle drift aquifer will intercept wastes from the area of coal-tar waste identified in the middle drift aquifer. Water pumped from the gradient control wells could be discharged to the sanitary sewer system or treated and discharged to Minnehaha Creek or a combination of these two disposal locations could be used, depending on the characteristics of the water. A second corrective measure examined is excavation. The study defines the volume of soil that must be excavated to remove various concentrations of phenolics and benzene extractable materials from the study area. Excavation is not presented as an alternative to gradient control, but rather as a means of reducing the time over which gradient control will be necessary. The unknown factors in determining the reduction in pumping time are the rate and amount of desorption of organics that could occur from the soil particles. A third corrective measure is the abandonment of all wells in the area that potentially act as recharge wells to a lower bedrock aquifer and the abandonment of St. Peter wells at the City's 29th Street and Idaho Avenue well field. Again, this corrective measure is not an alternative to gradient control in the middle drift but should be implemented in addition to gradient control. A fourth corrective measure that is discussed is the additional treatment of municipal water supplies by adsorption with activated carbon or other processes to remove the trace organics that have been periodically identified in samples from various municipal wells. Again, this corrective measure is not offered as an alternative to gradient management but as an action to be taken if further studies or experience show that the quality of water produced at municipal wells is not acceptable as a potable supply. Undoubtedly, other "innovative" measures to solve the various problems identified in this report will be suggested. During the study, various "innovative" measures were discussed; however, no other measure was identified with the degree of success as high as gradient control.

This section of the report has been divided into four subsections. The first subsection discusses gradient control including the location of the gradient control wells, the expected quality of ground water pumped from the middle drift aquifer, the two disposal routes that would seem to be available, and the additional data needed to design the system . The second subsection of the report discusses excavation and presents the quantities of soil that must be excavated to remove various concentrations of benzene extractable material and phenolics. The third section discusses abandonment of uncased bedrock wells in the area. The fourth section summarizes additional treatment that could be used at the municipal wells if organics identified at trace levels prove to warrant removal.

GROUND WATER GRADIENT CONTROL

The most logical ground water gradient control system is a system of pump-out wells that will collect contaminated ground water before it has a chance to move from the area. The two flow routes from the contaminated area of the glacial drift that have been identified are lateral movement through the middle drift aquifer and vertical movement to the Platteville with subsequent lateral movement through the Platteville, most likely to the buried bedrock valley. The analysis in Section IV of this report indicated that the flow from the contaminated area of the middle drift aquifer was likely to range from about equal to the lateral flow out of the middle drift aquifer to about five times the lateral flow out of the middle drift. Due to the unknown pattern of solution channels in the Platteville, it will be most effective to manage gradients in the middle drift aquifer and to control the lateral and vertical movement of ground water away from the contaminated area in that aquifer. As the piezometric levels are lowered in the middle drift aquifer, a portion of the flow in the Platteville will be diverted upward through the lower drift and captured by the gradient control wells.

Conceptual Design of Gradient Control System

The rate at which removal will occur is dependent upon the distribution of coal-tar waste in the soil, the rate at which the wastes will desorb from the soil particles, the hydrogeology of the drift and the location and pumping rates of the wells. For gradient control purposes, organic constituents typified by phenolics, polynuclear aromatic hydrocarbons, chemical oxygen demand, biochemical oxygen demand, and oil and grease are of interest. Of these parameters, phenolics have been analyzed most frequently, with three or more samplings at most monitoring wells since early 1976. Phenolic compounds are also considered to be representative of the more mobile portion of the coal-tar waste in the ground water. Therefore, the distribution of phenolic substances was used as the basis for designing the gradient control system. It has been assumed that areas with phenolic concentrations greater than 10 micrograms per liter would be included in the system.

The distribution of phenolics in the various ground water aquifers was discussed in Section IV of this report. A range in the distribution of phenolics in the middle drift aquifer was presented. This range is represented by the contours in Figures 16 and 17. For the purposes of conceptually

* distribution of middle aquifer source
① outside area
② vertical recharge

designing a gradient control system and estimating the rate at which phenolics will be removed by pumping, it was assumed that the concentration contours in Figure 16 are applicable. Gradient control system design and removal rates for conditions represented by Figure 17 will be similar. The assumed distribution of phenolics in Figure 16 was combined with an analysis of the hydrogeology of the middle drift aquifer to define the pumping rates and locations of the gradient control wells. The results of these analyses were then used to estimate the rate at which the phenolics would be removed from the middle drift aquifer.

It was concluded that the June portion of the study period would be most representative of the distribution of piezometric levels during periods of normal precipitation. Designing the gradient control wells on the basis of piezometric levels measured during the drought conditions prevailing over earlier portions of the study period may have resulted in a gradient control system insufficient to manage the gradients during more normal precipitation periods.

The water balance in the middle drift aquifer indicated that the vertical component of flow from the area with the high concentrations of phenolics around Well 13 is likely a significant source of phenolics to the Platteville limestone. Due to the difficulty in removing water from the Platteville limestone, it is recommended that a gradient control well be placed at the base of the middle drift aquifer immediately downstream of the zone of high phenolic concentrations to intercept ground water with the highest phenolics before it reaches the Platteville. This well is shown as Well A in Figure 22. Pumping this well at a rate of approximately 15 gpm should effectively intercept all the flow moving laterally and vertically through the 1,000 microgram per liter concentration contour as well as most of the flow moving laterally and vertically through the 100 microgram per liter contour upstream of the well under the June, 1977 distribution of piezometric levels in the glacial drift shown in Figure 14 and the distribution of phenolic contours shown in Figure 16. This area of influence is shown in Figure 22. Piezometric contours east of Well 11 had to be extrapolated due to the effects of the unknown pumping center on the contours measured June 15, 1977.

To intercept the lower concentrations of phenolics moving laterally in the middle drift aquifer east of the area of most concentrated coal-tar wastes as well as much of the contaminated seepage moving through the Platteville, two additional gradient control wells are recommended at the base of the middle drift aquifer in the eastern portion of the study area. These wells are labeled Well B and Well C in Figure 22. Pumping each of these wells at approximately 15 gallons per minute was estimated to intercept lateral flow in the middle drift aquifer between the streamlines shown in Figure 22 and to provide an upward gradient from the Platteville to the gradient control wells.

Pumping each gradient control well at a rate of 15 gpm is anticipated to result in a maximum drawdown on the order of 5 feet at each well. This should not cause any problems with settlement of structures.

There are two general ways to model the likely phenolic concentrations in ground water removed by the gradient control system. These are plug flow and completely mixed flow. In plug flow, it is assumed that no mixing of ground water occurs along the direction of flow. Ground water volumes closest to the well are removed first, followed by the ground water volumes at a greater distance. Removal of a contaminant from the aquifer is assumed complete after one volume of water has passed through the system. Thus, plug flow can be thought of as representing a lower limit for the time required to remove a contaminant from the ground water. In completely mixed flow, it is assumed that the water volume is homogeneously mixed at all times. Under these assumptions, concentrations are gradually reduced over time, and the time rate of removal becomes an exponential function. The time required to reach 99 percent of complete removal is calculated instead of the time required for complete removal since the latter is infinite. A completely mixed system can be thought of as representing an upper limit for the time required to remove a contaminant from a given volume neglecting the effects of desorption of material bound to soil particles. For the purposes of estimating the removal concentrations, it was assumed that the phenolic concentrations are constant within the aquifer in the vertical direction and vary linearly between the contours. For estimating purposes, phenolic concentrations were neglected in the areas outside of the 10 microgram per liter contour.

Although the models described above provide insight into the potential concentrations of phenolics and other parameters in discharges from the gradient control system and into the time period necessary for control, the available data are limited and uncertainties concerning permeability, aquifer recharge and leaching will affect the accuracy of the estimates. The assumption that ground water will move horizontally through the middle drift aquifer to the gradient control wells is dependent on permeabilities in the horizontal direction and on the amount of rainfall and recharge that occur. Leaching from other zones of contamination may also affect both the supply of coal-tar derivatives and the degree of mixing during removal. Vertical homogeneity, which is known not to exist, was also assumed in estimating the distribution and availability of organics in the middle drift aquifer. Finally, none of the analyses performed indicate the potential for interaction between soils and the organics. Desorption and other chemical reactions are likely to affect removal by increasing the availability of organics. Desorption of organics from soil particles will probably reduce the rate at which phenolic concentrations decrease after the peak, thereby increasing the concentrations experienced in later years over those predicted in the models. Uncertainties associated with spacial distribution of organics, leaching patterns and recharge sources will thus affect the phenolic concentrations in the effluent from the gradient control wells.

In practice, removal of organics from the middle drift aquifer will likely proceed by a combination of plug and completely mixed flow. Ground water closest to the gradient control wells will be removed in a manner similar to plug flow, but the actual rate of changes in phenolic concentrations in effluent from the gradient control wells is likely to fall between the two results obtained by the plug flow and completely mixed flow assumptions discounting the effects of desorption.

Using the distribution of phenolics and aquifer hydrogeology discussed in Section IV, the rate of removal of phenolics was modeled using the three 15 gpm gradient control wells at the base of the middle drift aquifer as shown in Figure 22. To indicate the extremes of the rate of concentration changes likely to be experienced, both plug flow and the completely mixed flow were modeled.

The results of the plug flow and completely mixed flow models are shown on Figure 23(a). The results of these analyses provide a basis for estimating the likely concentrations of phenolics in the discharge from the ground water gradient control wells and the time period necessary for removal, again without considering desorption of organics from soil particles.

To obtain a third measure of the rate of phenolic concentration change, the middle drift aquifer was idealized as a series of completely mixed volumes. In this model, the aquifer was split into volumes along the piezometric contours and streamlines indicated by a flow net analysis of the gradient control system. It was assumed that flow proceeds through the series of volumes with complete mixing in each volume at all times. Due to the complexity of the analyses and the importance of the discharge from Well A on the quality of water discharged from the gradient control system, the hypothesis of a series of completely mixed volumes was applied only to Well A. Figure 23(b) summarizes the results of the series of mixed volumes model along with the plug flow and completely mixed flow models to indicate the contrast.

The preceding analysis indicates that after an initial period of relatively low concentrations, phenolic concentrations are likely to rise to a peak, after which a gradual decrease will take place. On the basis of the available data, it appears that the rise to the peak phenolic concentration at Well A will probably begin during the first year. Peak phenolic concentrations will probably be in the range of 3,000 to 8,000 micrograms per liter over a period of about 1 to 1½ years. The concentration will likely drop to below 100 micrograms per liter after about 15 to 20 years of pumping from Well A. On the order of 50 to 100 years of pumping will likely be necessary to reduce phenolic concentrations below 10 micrograms per liter.

The discharges from Wells B and C, which are located east of Well A, will likely exhibit a peak phenolic concentration on the order of several hundred micrograms per liter, and maximum concentrations will likely occur between 4 and 11 years after pumping starts. The available data indicate that the peak concentration from Wells B and C should occur after the peak concentration from Well A and the peak could last for 3 years or more. Phenolic concentrations in the discharge from Wells B and C will likely drop to less than 100 micrograms per liter after 15 to 20 years of pumping and it will likely take about 60 to 120 years to fall below 10 micrograms per liter. It is once again stressed that the preceding analysis does not consider the effects of desorption of organics that will occur from the soil particles with changing equilibrium conditions. Desorption may tend to increase the necessary pumping time, but will likely have less effect on peak concentrations.

Since phenolic concentrations in the discharges from Wells B and C should initially be less than 100 micrograms per liter, discharge from Well A during the period of its peak phenol concentration will be diluted by a ratio of 1:3 if all wells are connected. In this case, the peak phenolic concentrations of the combined discharge will be on the order of 1,000 to 3,000 micrograms per liter.

Comparison of phenolic concentrations with concentrations of other organic constitutents is difficult because of the limited available data and because of the variability in the data. Data in Tables 6 through 8 are highly variable and suggest that simple ratios among different parameters do not exist. This likely reflects differences among chemical species and factors such as solubility; total available mass of each species; and ability of the organics to participate in sorption, chemical reactions, or other processes.

In an effort to establish some general basis of comparison between phenolic concentrations and concentrations of other parameters, peak and average concentrations of chemical oxygen demand, biochemical oxygen demand, polynuclear aromatic hydrocarbons and oil and grease were estimated using a combination of observed concentrations and judgement. Table 8 summarizes the estimates of potential phenolic concentrations and compares them with estimated concentrations of other parameters likely to be observed in the effluent from the ground water gradient control wells.

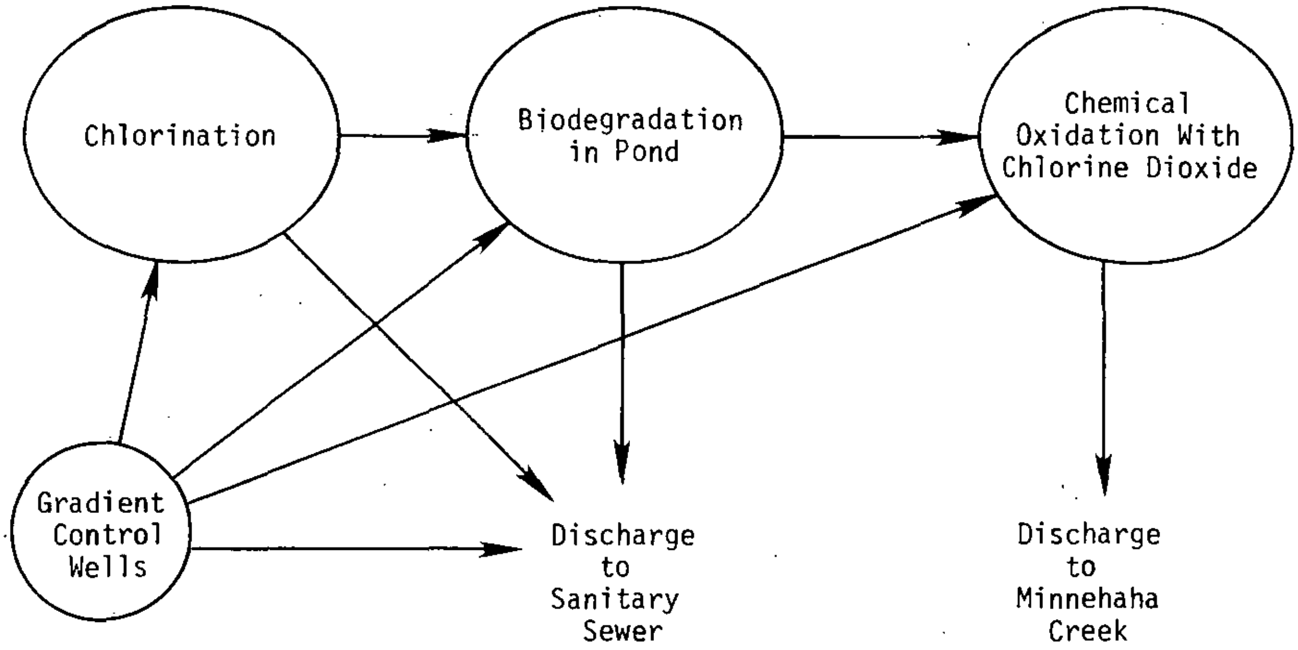
The estimated cost of the three gradient control wells is $8,000 to $10,000. This includes a 4-inch diameter casing, 8-foot long stainless steel well screen, submersible 20 gpm pump and electrical hook-up. The cost does not include piping to connect the wells. This cost is discussed in the next section.

If the actual distribution of phenolic concentration contours is found to be different than shown in Figure 16, the gradient control well concept will not change; however, the location of control wells B and C will need to be rotated so that these wells will capture ground water moving through the middle drift aquifer from the wetland area between Lake Street and Highway 7. The location of Well A should not change significantly.

Disposal of Ground Water

The purpose of this subsection is to discuss the disposal of ground water brought to the surface through the gradient control system. As a basis for identifying the ground water disposal alternatives and for their economic analysis, it is assumed that a gradient control system similar to that discussed in the preceding section will be implemented. The proposed locations of the three 15 gpm gradient control wells were given in Figure 22, and estimated peak and average concentrations of various organics were given in Table 8.

The disposal of ground water can be by two routes--discharge to the sanitary sewer or discharge to Minnehaha Creek after appropriate treatment. Alternatives can be devised that will use a combination of these two routes. For example, the more contaminated portions of the ground water can be diverted to the sanitary sewer while the less contaminated portions are discharged to Minnehaha Creek after treatment. The relationship among these disposal alternatives are summarized schematically below.



RELATIONSHIPS AMONG TREATMENT AND DISPOSAL OPTIONS

With any of these alternatives, disposal will be regulated. In the following paragraphs, the existing regulations, as well as the existing systems, that could be used to transport the effluent from the ground water gradient control wells are discussed. Modifications to the existing facilities that may be needed are also discussed.

Sanitary Sewer Disposal

Disposal to the metropolitan sewer system will be regulated by the Metropolitan Waste Control Commission (MWCC). MWCC regulations are based on quality and quantity considerations. The quality regulations are set forth in "Sewage and Waste Control Rules and Regulations for the Metropolitan Disposal System," published December 1, 1971. These regulations are being reviewed and will likely be revised in the future. Due to the unknown nature of any revisions, the existing regulations were used in this study. However, it should be recognized that MWCC regulations may change in the future, making it necessary to pretreat the effluent from the gradient con-

control wells prior to discharge to the sanitary sewer system. Potential treatment methods are discussed in Appendix F.

Various discharge limitations are included in the Rules and Regulations. Discharge limitations relevant to the discharge of ground water from the gradient control wells are summarized in Table 9. Additional provisions likely applicable to this discharge are included in Section 5-4 of the Rules and Regulations. These provisions restrict the disposal of water containing

> "unusually high concentrations of suspended solids, BOD, COD, or chlorine requirements...[and] any toxic substances, chemical elements or compounds, phenols or other taste or odor-producing substances or any other substances which may interfere with the biological processes or effiency of treatment works, or that will pass through a treatment works and cause the effluent therefrom, or the water into which it is discharged, to fail to meet applicable state or federal standards."

These provisions must be regarded as qualitative limitations due to the absence of quantitative criteria. For example, limitations on oil and grease are of concern where maintenance problems such as sewer plugging can result, and limitations on phenolic concentrations are of concern when resulting odors will present a nuisance (Madore, per. com.).

In addition to restrictions on the quality of discharges, the MWCC regulates discharges to the metropolitan sewer system through charges based on flow and quality. A service availability charge, a volume charge and a strength charge could be incurred as a result of the disposal of ground water from the gradient control wells to the sanitary sewer (Madore, per. com.).

The service availability charge is designed to pay for debt service which the MWCC has accumulated as a result of construction of reserve disposal capacity. It is a one-time charge assessed at the time of sewer connection. For 1977, the charge is $375 for each new 100,000 gallons of waste water added to the metropolitan sewer system on an annual basis. A discharge rate of 45 gpm would amount to a service availability charge of about $90,000. The service availability charge is intended to apply to long-term or permanent discharges. Since it is anticipated that the quality of ground water pumped from the gradient control wells will improve over time, discharge to the sanitary sewer may not be necessary over the long-term and the entire discharge eventually could be routed to Minnehaha Creek after adequate treatment. In addition to this potential capital cost, it is estimated that sewer connections will cost about $8,000.

The sewage volume charge is based on metered sewage flows and sewage disposal costs. These costs are estimated for each year on the basis of recorded sewage flows and costs associated with the disposal system during the previous year. Local sewer maintenance costs paid by the municipality are added to the volume charge to obtain the total volume charge. During 1976, the total volume charge for the City of St. Louis Park amounted to slightly more than 47¢ per 1,000 gallons (Hanson, per. com.). Therefore, continuous disposal of 45 gpm into the sanitary sewer will result in a total volume cost of approximately $11,000 per year. During 1977, it is expected that the total volume charge will rise due to inflation and increased treatment costs.

The strength charge is based on the concentrations of suspended solids and chemical oxygen demanding substances in the discharge. These two parameters, along with wastewater volume, are related to a strength charge by a formula established by the MWCC. This charge is designed to reflect the added treatment cost for high strength wastes and to place an appropriate financial burden on dischargers of those wastes. The annual strength charge is currently computed as:

$$\text{Annual Strength Charge} = (\$172.78)\ (V)\ (0.5444) \left[\frac{0.50(SS-317)}{317} + \frac{0.50(COD-681)}{681}\right]$$

where: V = total volume of waste discharged to sewer annually (millions of gallons)

SS = average suspended solids concentration in the discharge (mg/l), and

COD = average chemical oxygen demand concentration in the discharge (mg/l).

The constants used in this formula were determined for 1977 from the most recent MWCC operational records. It is anticipated that the constants will be revised annually. Credits are not given for suspended solids concentrations less than 317 mg/l or chemical oxygen demand concentrations less than 681 mg/l.

Since the concentration of suspended solids in ground water will likely be less than 317 mg/l, the strength charge will likely arise from chemical oxygen demand. If the average annual chemical oxygen demand is 1,000 mg/l, the annual strength charge will be about $500. If the average annual chemical oxygen demand is 2,000 mg/l, the annual strength charge will be about $2,200. This should bracket the strength charge during the years of peak concentrations in the combined discharge from the three wells. During most years, it is estimated that the concentration of COD from the three wells combined would be less than 681 mg/l, in which case there will be no strength charge during those years.

The St. Louis Park sanitary sewer system map indicates there is a gravity sewer in the vicinity of the proposed gradient control wells that could be used for the disposal of ground water to the metropolitan sewer system. This local sewer is owned and maintained by the City. The location of the sewer system is shown in Figure 24. The sewer system includes a 12-inch to 15-inch gravity sewer running northeastward along Lake Street then southeastward along Hampshire Avenue from the intersection of Lake Street and T.H. 7. It crosses the Chicago, Milwaukee, St. Paul and Pacific Railroad and discharges to St. Louis Park's Lift Station No. 2 on Edgewood Avenue. Although existing capacity data are not available for this sewer, it is the opinion of St. Louis Park Water Department personnel that sufficient capacity does exist for a discharge of 45 gpm (0.065 mgd) (Tolefsrud, per. com.). Lift Station No. 2 normally handles about 0.7 mgd and has sufficient pump capacity for about 5.6 mgd. Therefore, sanitary sewer disposal of the discharge from the gradient control system should not exceed the capacity of the existing sanitary sewer system. From Lift Station No. 2, the sewage flow enters the Hopkins forcemain which is a part of the metropolitan sewer system discharging to the Metropolitan Treatment Plant (Tolefsrud, per. com.).

The location of the sewer proposed for use is isolated from residential areas, so odors from the phenolic wastes are not likely to be a problem to residents. Property along Lake Street and Hampshire Avenue has been developed for light industrial use, and the lift station on Edgewood Avenue is located on an isolated site near Methodist Hospital. The sewer is about 25 feet below the ground surface in many sections (Tolefsrud, per. com.).

Discharges to Minnehaha Creek

Point discharges of wastes to Minnehaha Creek are regulated by the Minnesota Pollution Control Agency. Agency regulations would be implemented through issuance of a National Pollutant Discharge Elimination System (NPDES) permit for the point discharge and through issuance of a disposal facility permit for the treatment facility. A discharge permit would establish permissible concentrations or total loadings of various parameters in the effluent, as well as the monitoring requirements to demonstrate compliance with the permit. St. Louis Park has been issued a NPDES permit (MN 0045489) to discharge treated storm water to Minnehaha Creek from a treatment facility that treats surface drainage from the site of the former coal-tar distillation and wood preserving facility and adjacent areas. Thus, at least an initial base for estimating applicable limitations has been established for the discharge of coal-tar derived wastes to Minnehaha Creek.

Effluent parameters regulated under the discharge permit include phenolics, various polynuclear aromatic hydrocarbons, metals and other parameters associated with wastes from the coal-tar distillation and wood preserving facility. The effluent limitations in the discharge permit are expressed in terms of permissible daily maximum concentrations that depend on the flow in Minnehaha Creek. The permissible daily concentrations are summarized in Table 10. Comparison of the effluent limitations in Table 10 with the predicted quality of ground water from the gradient control system in Table 8 indicates that treatment for the removal of organics will be required before discharge to Minnehaha Creek.

The existing storm water conveyance system includes a storm sewer system, two Hypalon-lined storage ponds, and a lift station with a discharge to Minnehaha Creek. The total drainage area tributary to the storm sewer system includes the 80-acre site of the former coal-tar distillation and wood preserving facility and 220 acres of adjacent residential and industrial area. The storm sewer system is shown in Figure 24. According to the plans, the north pond has an area of 3.3 acres and a total storage volume of 23 acre-feet and the south pond has an area of 4.9 acres and a total storage volume of 44 acre-feet. Flow between the two ponds is controlled by the outlet of the north pond at Elevation 886.3.

The storm water treatment system that is designed to remove organics from the storm water prior to discharge to Minnehaha Creek is centered around the lift station located southwest of the south pond. The lift station has two pumps--one of 10,000 gpm capacity and the second of 5,000 gpm capacity that has been throttled to 2,500 gpm. The pumps are controlled by automatic float controls. With low intensity and short duration rainfall events, the system is designed to collect storm water runoff in the two ponds and discharge it on an intermittent basis at 2,500 gpm. With more intense runoff conditions, the 10,000 gpm pump would be used to prevent flooding. The pump controls are set to maintain the level of the south pond between Elevation 885.5 and Elevation 888.5.

To meet the effluent limitations in the NPDES permit, a treatment facility was designed to oxidize organics using a combination of chlorine and chlorine dioxide followed by dechlorination by sulfur dioxide. Chemical supplies and metering equipment are located in the lift station southwest of the south pond. Feed lines carry a chlorine-chlorine dioxide mixture to an injection point at a bar screen in the storm sewer about 200 feet upstream of the lift station. The sulfur dioxide is added in the wet well before the pumps. With a flow rate of 2,500 gpm, hydraulic residence time between chlorination and dechlorination will be approximately 6 minutes. During this time, oxidation of organic compounds can take place.

Available information indicates that the treatment system was designed to oxidize 90 pounds of phenolics per day at a concentration of 3 mg/1.

Although the chemical feed rates were reportedly adjusted and tested to insure compliance with project specifications, there is no data available on chemical feed rates or on the ratio of chlorine dioxide to phenolics or other aromatic hydrocarbons needed to meet permit requirements. Chlorination of surface runoff apparently has not been necessary to meet the permit requirements. Since the chlorination facility has not been necessary, the supplies of chlorine and sulfur dioxide have been returned to suppliers. In the absence of data to the contrary, it has been assumed for the purposes of this report that the existing treatment facility is capable of meeting the requirements of the NPDES permit requirements under the design criteria of 90 pounds per day of phenols destroyed at an inflow phenolic concentration of 3 mg/l. Oxidation by chlorine dioxide and other potential treatment methods are discussed in Appendix F.

Discharge of effluent from the gradient control wells to the existing storm water conveyance and treatment system would provide treatment by biodegradation in the south pond and chemical oxidation at the treatment facility. Since the chemical feed apparatus is designed to oxidize 3 mg/l of phenols to an effluent phenolic concentration of 0.01 mg/l at a 2,500 gpm pumping rate, it could be assumed that the design is sufficient to oxidize phenols and other organic compounds for most, if not all, of the ground water gradient control period. However, the data indicate that organic concentrations may be quite different in the ground water than in the surface water. For this reason the oxidation requirements may be different for the destruction of organics in the effluent from the gradient control wells than from the assumed quality of surface runoff used to design the existing treatment facilities.

There are several modifications to the system that may be necessary to provide the necessary additional treatment. The necessity of additional treatment will depend on the results of the recommended bench scale and pilot scale tests using water generated by the gradient control wells. Various disposal alternatives are shown on Figure 25.

One modification would be to use the south pond or a new pond to biochemically oxidize the effluent from the gradient control wells. For example, if the controls on the lift station pumps are adjusted to keep the south pond between Elevation 885.3 and 886.3, the mean hydraulic residence time for a continuous 45 gpm inflow would be approximately 150 days. If the average ultimate BOD of the inflow from the gradient control system is less than 1,600 mg/l, as seems likely, the organic loading to the south pond would be less than 200 pounds per acre per day. These hydraulic and organic loading rates are within the standard oxidation pond design criteria (McGauhey, 1968), and, therefore, a reasonable degree of treatment could be expected with the use of the south pond. Difficulties with this concept are the uncertain treatability of the coal-tar derivatives, the complicating effect of storm water discharges to the pond and the need to keep the pond aerobic.

Results of various studies (Stearns et al., 1977) indicate that successful biodegradation of coal-tar derivatives will require aerobic decomposition. During ice-free periods, oxygenation of the south pond by atmospheric transfer should be sufficient to meet demand, especially during windy periods. Since the south pond has a depth of about 8 feet under normal conditions, thermal stratification is unlikely and the pond should be well mixed during ice-free periods. However, the potential for hydrocarbon sludge separation over the long-term and oxidation inhibition due to winter ice cover would seem to make the use of a simple compressed air mixing system advisable, at least during the period of elevated organic concentrations in the inflow from the gradient control wells. Such a pond aeration system should cost on the order of $120,000--including installation, engineering and contingencies--if the lift station is used to house the compressor and controls. Operation and maintenance costs would probably be on the order of $12,000 a year, primarily because of the power costs for the blowers. In addition, there would be annual costs for chemical feed equipment and chemicals which could not be estimated for this study due to the lack of data on chemical feed rates.

A possible modification to the existing lift station would be to add a new lift station pump with a capacity of something less than 2,500 gpm. This would provide a higher ratio of oxidants to organics and increase the reaction time during which oxidation can take place. This would be necessary if pilot scale studies show that insufficient oxidation of effluent from the gradient control wells occurs to meet effluent standards using the existing 2,500 gpm capacity pump. For example, a 500 gpm capacity pump could be provided. Under this system, the oxidant to organics ratio and the reaction time would be increased by a factor of 5 over that provided by the 2,500 gpm capacity pump.

In general, use of the existing storm water ponding area for the disposal of effluent from the gradient control system has several disadvantages. First, mixing between surface water runoff and ground water will likely result in widely varying concentrations of phenolics and other organics depending on the surface runoff volume and hydrograph shape. As a result, chemical feed rates will need frequent adjustment unless the pond effluent was simply over-chlorinated by a significant margin. Use of the storm water pond as an oxidation pond for gradient control effluent would also result in the accumulation of solids and could cause odor problems due to volatilization of the coal-tar wastes and/or anaerobic growth if sufficient aeration is not provided. An advantage of using the existing pond without modification would be a reduction in capital cost compared to building a separate pond.

As an alternative to the discharge of gradient control effluent to the storm water pond, the effluent could be pumped directly to a chemical oxidation facility and discharged to Minnehaha Creek. This could include the construction of a new chemical treatment facility to oxidize the effluent from the gradient control wells or could include expansion of the existing chemical feed equipment to chlorinate both well effluent and storm water runoff through separate contact chambers. With this latter alternative, it would likely be best to provide a separate package lift station and pumps to discharge effluent from the gradient control wells. The storm water and gradient control effluent lift stations could be served by the same chemical generation and feed equipment. Controls could be installed to shut down the gradient control wells and shift the chemical feed to the treatment of storm water runoff during periods when the lift station must be used to discharge storm water. The capital cost of providing the necessary piping and pump capacity with this alternative would be on the order of $70,000. Operating and maintenance cost would be on the order of $2,000 per year, plus expenses associated with chemical feed equipment and chemicals which could not be estimated.

Use of separate treatment systems for surface water and ground water has the advantage of keeping gradient control effluent out of the storm water ponding area and would provide a basis for more constant chemical feed rates. However, separate systems would require the construction of a force main between the wells and the treatment facility instead of just between the wells and the storm sewer system. The general locations of the various alternatives discussed in this section are shown on Figure 25. The monitoring of effluent discharged to Minnehaha Creek will be a significant cost. Based on a biweekly sampling of effluent and analysis for the parameters in the existing NPDES permit, the monitoring cost is estimated to be on the order of $10,000 per year.

Combinations of Sanitary Sewer and Surface Water Disposal

As alternatives to complete disposal of the gradient control effluent to the sanitary sewer or to Minnehaha Creek after treatment, a number of possible combinations of these two routes could be used to dispose of gradient control effluent. Combinations could take the form of either:

1. discharging all gradient control effluent to the sanitary sewer system during a selected period, such as initially, until sufficient data is collected to assess the actual concentrations and treatability of organics in the effluent, or during years of peak concentrations of organics in the effluent;

2. disposal of the effluent from gradient control Well A to the sanitary sewer system with disposal of effluent from Wells B and C to Minnehaha Creek after treatment.

The major advantage of connecting the gradient control system to both discharge routes is the flexibility that will be provided. Considering the uncertainties in the predicted quality of the gradient control effluent, initial discharge of all ground water to the sewer would enable additional data to be collected. Data collected during the initial period could be used to better define waste treatability and to better define specific problems that are likely to arise in using the available storm water treatment system. The initial period could also be used for bench scale and pilot scale testing to determine proper chemical feed rates and residence times for oxidation with chlorine dioxide or other chemicals.

The capital and operating costs of a system that combines the two disposal routes will, of course, depend on the actual combination that is selected. It is possible, for example, that diversion of the most contaminated effluent to the sanitary sewer would be needed for only a short period, thus avoiding the MWCC Service Availability Charge, and that remaining effluent could be treated in the existing system. In that case, the cost of disposing the effluent from the gradient control wells would be much less than given previously. The cost estimates indicate that outlays on the order of $100,000 for capital cost and $10,000 per year for operation and maintenance (excluding chemical feed equipment and chemicals) represent an approximate upper limit for disposal.

Additional Data Needed to Design Gradient Control System

The data available for this report were sufficient to evaluate the technical feasibility of the gradient control concept; however, before the ground water gradient control system can be designed, it will be necessary to collect additional data regarding ground water movement and quality in the glacial drift. The locations of the suggested wells and piezometers are shown on Figure 34.

Additional soil borings and ground water piezometer nests are necessary east of the site to define the effect of piezometric levels in this area on the movement of ground water through the middle drift. Specifically, it is recommended that soil borings and piezometers be placed near the intersection of Louisiana Avenue and Jersey Avenue, near the intersection of Republic Avenue and First Street N.W. and near the intersection of Brownlow Avenue and Lake Street. The soil borings should be placed to bedrock. Soil samples from the borings should be visually classified to define the stratigraphy, especially of the middle drift aquifer. Grain size distributions should be determined for soil samples in the middle drift aquifer to define the permeability of this aquifer. Two piezometers should be placed in each soil boring, one in the middle drift aquifer and one in the lower drift near the bedrock contact. Ground water levels in all piezometers should be measured and the data used to refine the interpretations of ground water movement through the middle drift aquifer presented in Section IV.

A piezometer should be placed in the peat soils above the first till layer in the vicinity of Well 13. The purpose of this piezometer is to obtain information on water level fluctuations in the upper drift to better estimate water level changes in this unit as a function of precipitation.

Additional monitoring wells will also be necessary to better define glacial drift ground water movement and quality prior to design of the gradient control system. Specifically, wells in the middle drift aquifer and in the lower drift are recommended near the intersection of South Street and Louisiana Avenue, near the intersection of Oxford Street and Edgewood Avenue, along Oxford Street between Well 10 and Edgewood Avenue and along Lake Street between Wells 8 and 9. Samples should be collected from these wells and analyzed for phenolics and polynuclear aromatic hydrocarbons. These data should enable a more precise location of the phenolic concentration contours presented in Section IV. A better definition of the phenolic contours is necessary to define the most effective locations for gradient control wells B and C. In addition, ground water monitoring wells in the middle drift aquifer and lower drift near the intersection of Republic Avenue and Second Street would be desirable to better define the quality of ground water in these two units in this area. These data are needed to define the northeastern limits of the phenolic concentrations. If phenolic concentrations in excess of 10 micrograms/liter are identified in either of these wells, additional wells to the northeast will be necessary.

In addition, wells in the middle drift aquifer and in the lower drift should be placed along Colorado Avenue and along West 36th Street between the present limits of the study area and the buried bedrock valley. These wells are not shown on Figure 34. If these wells show phenolic concentrations in excess of 10 micrograms/liter, additional wells should be placed in the appropriate glacial drift units closer to the buried bedrock valley. The objective of this program is to better define the eastward limit of the 10 microgram/liter phenolic concentration contour.

After the effect of the area east of the site on ground water flow in the middle drift aquifer has been defined and after the phenolic concentration contours have been more accurately located, the best locations for the gradient control wells can be estimated. One or more test wells and, if existing wells cannot be used, monitoring wells should then be installed and the test wells pumped to verify middle drift aquifer characteristics. Based on the test pumping data, the gradient control wells can be designed and located.

If disposal of effluent from the gradient control wells is to be by discharge, at least initially, through the sanitary sewer system, the only waste treatability data that will likely be needed will be that needed by the MWCC to assess strength charges. If, however, disposal is through either the existing surface water treatment facility or a new treatment facility, significant additional treatability data will be required prior to treatment facility design. In some respects, however, design of the treatment facility for effluent from the gradient control wells should be easier than the design of the surface runoff treatment facility since samples of the ground water are available for bench scale treatability testing, whereas the characteristics and, therefore, the treatability of surface runoff had to be estimated.

The available data indicate that concentrations and ratios between concentrations of the various organics in the waste are variable. This is likely to continue during gradient control, since the various organic compounds will desorb from drift materials at different rates, since solubilities vary among the organic compounds and since uncertainties in the hydrogeologic analyses will affect any estimate of removal rates. Considering this variability, it will likely not be possible to generate data that will accurately describe the treatability of the ground water over the life of the project and flexibility to meet changing quality must be built into the system.

During operation, the effectiveness of the gradient control system should be monitored. Monitoring of the effectiveness of the wells should be carried out by measuring changes in gradients within the controlled area and by measuring the changes in water quality downstream in the middle drift aquifer and in the Platteville.

EXCAVATION OF CONTAMINATED SOIL

The purpose of this subsection is to summarize the volumes of soil that would have to be removed from the contaminated areas to remove various concentrations of benzene extractable and phenolic materials in the soils. Excavation is not intended to be an alternative to gradient control since ground water high in phenolics and other organic materials has moved out of the area of contaminated soil. However, excavation of soil from areas high in phenolics or benzene extractable material may tend to decrease the time necessary to control the ground water gradients in the area south and east of the site. The amount of decrease, however, is not predictable.

The assumptions made in constructing the removal depth contours and in computing the soil volumes were as follows:

1. Data used to develop the contours were derived completely from cross-sections in the Phase I Report.

2. Side slopes of the excavation were assumed to be 2 feet horizontal to 1 foot vertical. The assumption was used where contours in the Phase I Report did not extend to the surface and in the deeper areas of the excavation. The side slope assumption, however, makes very little difference due to the accuracy of the data and due to the fact

that the concentration gradients themselves are greater than 2:1.

3. Buildings were ignored in computing excavation volumes.

The resulting contour maps were used to develop order of magnitude estimates of the volume of material that would be removed. No attempt has been made to put a cost on the excavation.

The approximate volumes of soil that would have to be removed to remove soils with phenolic concentrations between 1 mg/kg and 100 mg/kg are shown on Figure 27. The removal depth contours for removing soil with phenolic concentrations greater than 1 mg/kg, 10 mg/kg and 100 mg/kg are shown on Figures 28 through 30. As shown in Figure 30, the excavation of soils containing phenolic concentrations greater than 100 mg/kg is concentrated in a rather narrow area between Walker Street and Lake Street south of the site. The removal of soils with phenolic concentrations greater than 10 mg/kg is concentrated in the same area between Walker Street and Lake Street with a small excavation area needed around Boring 4 in the area of the old API separator. The excavation to remove soil with phenolic concentrations greater than 1 mg/kg will reach a depth of over 60 feet between Walker Street and Highway 7 with a 20-foot depth removal contour extending up into the southern portion of the site. (ACCURACY)?

The approximate volumes of soil that must be excavated to remove soil with benzene extractable concentrations between 1,000 mg/kg and 100,000 mg/kg are also shown on Figure 27. The excavation contours for removing soil with concentrations of 1,000 mg/kg, 10,000 mg/kg and 100,000 mg/kg are shown on Figures 31 through 33. As with the excavation contours for removing soil with phenolics, the excavation area to remove soil with the highest concentrations of benzene extractable material is concentrated in the area between Walker Street and Lake Street, south of the site. Excavation limits to remove soils with benzene extractable concentrations greater than 10,000 mg/kg, however, do extend into the southern part of the site and excavation contours to remove soil with benzene extractable in excess of 1,000 mg/kg encompass practically the entire site. Maximum depth of excavation to remove 1,000 mg/kg of benzene extractable material is 30 feet.

ABANDONMENT OF UNCASED WELLS

The preceding analyses have shown that the most likely reason for detectable phenolic concentrations in the St. Peter, Prairie du Chien-Jordan and Mt. Simon-Hinckley aquifers are uncased wells that provide flow paths between the glacial drift/Platteville and these underlying bedrock aquifers. Thus, an important corrective measure that should be implemented immediately is to locate and plug all wells that have the potential of providing flow paths between the drift/Platteville system or the St. Peter aquifer and the underlying bedrock aquifers. This general recommendation was made by Sunde (1974) and is made again in this report.

The problem will be to find all the wells that provide a flow path from the upper to the lower aquifers. It is likely that studies carried out to date have identified all wells for which logs are publicly available. A great deal of effort will be involved in locating wells for which no logs are publicly available. Studies carried out for this report indicate there likely are wells in the study area that are no longer used but are unrecorded. It is likely that many of these wells are very old and, therefore, probably only cased to the first bedrock contact. The highest priority should be given to locating all wells in the area extending from Texas Avenue on the west to Minnehaha Creek and Excelsior Boulevard on the south to Highway 100 on the east to Minnetonka Boulevard on the north. Water well contractors who have worked in the area should be contacted. Experience has shown that well contractors have knowledge of well locations for which there is no public information. All leads obtained from well contractors should be followed up by talking to property owners or current residents of the property. Present property owners in the high priority investigation area should be contacted and inquiries made regarding the existence of wells on their property.

Information from well contractors and property owners should be vigorously followed up to locate existing wells. This may, in some instances, require the removal of floors or the excavation of soil. Wells in the high priority area of investigation that are located should be abandoned according to the Minnesota Water Well Construction Code if they are not being used or if there is a chance they could provide a flow path between either the drift/Platteville and the lower bedrock aquifers or between the St. Peter and the lower bedrock aquifers.

ADDITIONAL TREATMENT OF MUNICIPAL WATER SUPPLIES

In 1973-1974 and again during testing for this study, very low, but detectable concentrations of phenolics have been measured in water samples from St. Louis Park municipal wells. Information generated in this study seems adequate to explain measured concentrations in City Mt. Simon-Hinckley wells, but inadequate to attribute phenolics in the St. Peter or Prairie du Chien-Jordan wells to coal-tar wastes from the former coal-tar distillation and wood preserving facility. In any event, the phenolic concentrations in the City wells should be monitored on a quarterly basis. If phenolic tastes or odors become a problem or if other problems with the trace organics are identified, a mitigative measure could be treatment of the water supply by activated carbon adsorption. The purpose of this subsection is to examine the use of activated carbon treatment in a very preliminary manner.

who!

It appears that carbon adsorption could be implemented by modifying the City's existing water filtration system. About 18 inches of the existing sand filtration media could be replaced by granulated activated carbon. Thereafter, the carbon would have to be replaced periodically as the adsorption capacity of the media was exhausted. The exact cost would depend on the number of filtration units so treated. The existing capacity includes about 6,000 square feet of filters, and modification of the entire capacity would cost about $180,000 for activated carbon alone (Netz, per. com.). The additional costs of removal and disposal of the existing media are very difficult to estimate since hand labor would be required almost exclusively. After modification, periodic replacement of activated carbon would be mechanically implemented by carbon suppliers using vacuum trucks. Frequency of replacement would depend on flow rate and on the concentrations of organics and other absorbates in the water. According to information in the literature (CH2M/HILL, 1973; Patterson, 1975), removal of phenols at initial concentrations of 20 μg/l could take from 17 to 870 cubic feet of fresh activated carbon per million gallons. At $20 per cubic foot, this amounts of $0.34 to

$17 per thousand gallons. Thus, in comparison to the control of gradients in the glacial drift aquifer, treatment of municipal water supplies could be extremely expensive. This suggests that it will be much easier and more cost-effective to remove the identified coal-tar wastes at the present time, than to continue to allow them to migrate away from the contaminated area laterally through the middle drift aquifer and Platteville limestone.

SECTION VII

CONCLUSIONS AND RECOMMENDATIONS

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CONCLUSIONS

Based on the analyses carried out in this study, the following conclusions are made:

1. Analytically detectable quantities of coal-tar derivatives were present in approximately 90 percent of the soil samples collected and analyzed during this study. Coal-tar derivatives are present in much greater concentrations throughout the soil column on the southern portion of the coal-tar distillation and wood-preserving site and south of the site than on the northern one-half of the site. For example, benzene extractable concentrations greater than 1,000 mg/kg are present at a depth of 50 feet south of the site, whereas they are typically present at concentrations between 100 mg/kg and 200 mg/kg below the surface soils on the northern portion of the site. Chrysene, benz(a)pyrene, benz(c)phenanthrene and a number of other unidentified polynuclear aromatic hydrocarbons are present in the visible coal-tar wastes found near the surface throughout the study area and at depth south of the site. No attempt was made in this study to define the public health risks associated with these materials in the soil.

2. Ground water in the glacial drift south and southeast of the site is moving laterally through the outwash material and vertically into the Platteville limestone. Vertical flow to the Platteville in the area southeast of the site is equal to or greater than lateral flow through the outwash. Ground water movement through the Platteville is lateral, most likely toward the buried bedrock valley southeast of the site.

3. Ground water in the glacial drift south and southeast of the coal-tar distillation and wood-preserving site is contaminated with coal-tar derivatives. From its point of deposit by surface flows, the movement of the waste has been lateral with ground water flow and vertical due to its higher specific gravity and due to the vertical ground water movement. The wastes contain measurable phenolics and polynuclear aromatic hydrocarbons such as pyrine. Polynuclear aromatic hydrocarbon concentrations of 3,400 mg/l and phenolic concentrations of 50 mg/l have been detected at a depth of 50' below the ground surface in the area between Lake Street and Highway 7. These wastes have traveled at least 1,000' to the southeast and to the glacial drift/bedrock contact where polynuclear aromatic hydrocarbon concentrations of 1.7 mg/l and phenolic concentrations of .3 mg/l have been measured. Thus, it can be concluded that phenolics and polynuclear aromatic hydrocarbons are contained in ground water reaching the Platteville limestone over at least a portion of the area southeast of the site. No attempt has been made in this study to define the public health risks associated with these materials in the ground water.

4. Phenolic concentration contours in the glacial drift south and southeast of the site are likely moving southeastward at rates between 30 and 150 feet per year. Ground water quality in the glacial drift aquifer is not at a steady-state condition and the concentration of coal-tar derivatives will continue to increase away from the area of concentrated coal-tar waste. Reasonable estimates of flow through the Platteville limestone indicate that water in the Platteville takes on the order of 20 to 50 years to reach the buried bedrock valley from the area southeast of the site although flow times could be much less. The quality of water moving through the Platteville is also not at a steady-state condition and the concentrations of coal-tar derivatives will likely continue to increase.

5. The buried bedrock valley southeast of the site is a recharge area to the St. Peter sandstone. Ground water reaching the buried valley either through the glacial drift or the Platteville can enter the St. Peter sandstone. From the buried valley, movement will likely be eastward out of the study area. The potential effect of this movement was not determined.

6. A number of wells in the area are uncased through two or more bedrock aquifers and thus provide potential pathways for ground water to move between the upper more contaminated aquifers such as the glacial drift and Platteville and the lower aquifers.

7. Data collected for this study supports earlier data that indicate very low, but detectable concentrations of phenolic compounds in bedrock wells beneath the site and at a municipal well field located north of the site. The very low concentrations of phenolics in the St. Peter sandstone measured south and southeast of the site can be attributed to leakage through the Glenwood or to leakage through uncased wells. The trace phenolic concentrations measured in the Mt. Simon-Hinckley wells on the site and at the City's well field are attributed to movement of coal-tar derivatives from a Mt. Simon-Hinckley well on the site to the municipal well field. The available information, however, is not sufficient to explain the reason for the measured phenolic concentrations in the municipal St. Peter and Prairie du Chien-Jordan wells at the municipal field north of the site or at other municipal well fields in the area. In the case of the St. Peter wells, the gradients are sufficient to transmit seepage from uncased wells to the municipal well field; however, the time since construction of the uncased wells is too short for these wells to be the source of phenolics in the municipal wells. In the case of the Prairie du Chien-Jordan wells, the computed gradients indicate that ground

water cannot be transmitted from the site to the municipal well field north of the site.

8. Since the quality of the water in the glacial drift and Platteville is not at a steady-state condition, the quality of water in the St. Peter aquifer, which is influenced by seepage from the glacial drift/Platteville, is also not at steady-state. Due to its greater distance from the area of waste concentration in the glacial drift, the quality of the water in the St. Peter will change more gradually than the quality of water in the drift or Platteville. Since the quality in the Prairie du Chien-Jordan cannot be explained by the available data, no comments can be made about future changes in the quality of water in this aquifer. The quality of the water in the City's Mt. Simon-Hinckley wells is likely controlled by recharge through uncased Mt. Simon-Hinckley wells. Since future ground water quality around these uncased wells should not change significantly, it can be concluded that quality of the Mt. Simon-Hinckley aquifer has, for practical purposes, reached a steady-state condition. Thus, very little change in the quality of this aquifer is anticipated due to the wastes discharged from the former coal-tar distillation and wood-preserving facility.

9. The coal-tar derivatives in the glacial drift ground water system represent a potential threat to the underlying ground water aquifers due to the uncased wells, due to flow to the buried bedrock valley, due to seepage through the Glenwood and due to the fact that existing industrial wells that acted as barriers to waste movement down-gradient of the contaminated ground water are being abandoned, thereby increasing the potential for the spread of the identified wastes.

10. The control of ground water movement in the glacial drift to prevent the spread of the coal-tar derivatives is technically feasible using a system of pump-out wells in the glacial drift to control ground water gradients. The system investigated in this study assumed one well placed in the area of severest contamination in the wetland area north of Lake Street and south of Highway 7 and two wells located to the east and southeast. The western gradient control well will remove the severest contamination that is likely the source of most coal-tar derivatives detected in this study. The eastern two wells will remove material that has escaped from this source and is traveling either through the drift or Platteville. Peak phenolic concentrations in the discharge from the well system are predicted to be on the order of 1 to 3 milligrams per liter and peak polynuclear aromatic hydrocarbon concentrations are predicted to be on the order of 100 milligrams per liter. Concentrations of phenolics from the system are predicted to be less than .1 milligrams per liter after about 15 to 20 years of pumping while on the order of 50 to 100 years will likely be necessary to reduce phenolic concentrations below .01 milligrams per liter. The effect of desorption from soil particles could not be quantified, but will likely increase the pumping needed to reach these concentrations.

STANDARDS OR WHAT? ★

11. The sanitary sewer and the existing surface water treatment and disposal system were evaluated as disposal routes for the effluent from the gradient control wells. The most logical route for the effluent during times that high phenolic concentrations are produced will be the sanitary sewer. Sanitary sewer disposal is estimated to cost on the order of \$10,000 to \$15,000 per year. A service availability charge of approximately \$100,000, however, could be assessed by the Metropolitan Waste Control Commission if the discharge is judged to be

permanent. The second disposal route is the existing treatment facility that is in place to treat storm water runoff from the site prior to discharge to Minnehaha Creek. In concept, the existing treatment system could provide the required treatment. Bench scale and pilot scale studies will be needed to determine if modifications to the existing facility will be necessary to treat the effluent. Combinations of these two disposal routes are possible, such as disposal of effluent from the western gradient control well to the sanitary sewer system and disposal of effluent from the eastern wells to the existing surface water treatment facility.

12. The volumes of soil that must be excavated to remove various concentrations of phenolics and benzene extractable material in the soils were evaluated. On the order of 700,000 cubic yards of soil must be excavated to remove all soil with phenolic concentrations greater than 1 mg/kg. On the order of 400,000 cubic yards of soil must be excavated to remove soils with benzene extractable concentrations greater than 1,000 mg/kg. Excavation of contaminated soil is not an alternative to gradient control. Excavation of the most contaminated soils will, however, reduce the time required to control gradients in the area. The amount of time reduction, however, is not quantifiable.

RECOMMENDATIONS

Based on the analyses carried out for this study and on the preceding conclusions, the following recommendations are made:

1. All bedrock wells constructed so as to provide pathways for ground water to move between the drift/Platteville and St. Peter and between the St. Peter or Prairie du Chien-Jordan and Mt. Simon-Hinckley aquifers should be grouted and abandoned. Highest priority should be given

to locating and abandoning wells in the area bounded by Texas Avenue on the west, Minnetonka Boulevard on the north, Highway 100 on the east and Minnehaha Creek and Excelsior Boulevard on the south. Wells in this area should be located and abandoned immediately. The investigations summarized in this report indicate that these wells present potential pathways for the movement of coal-tar derivatives to the lower aquifers and, in fact, represent the only reasonable means by which ground water in the Prairie du Chien-Jordan and in the Mt. Simon-Hinckley formation could be contaminated with waste from the site of the former coal-tar distillation and wood-preserving facility.

2. Since the abandonment of uncased wells near the site will likely result in the movement of recharge from the buried valley to the St. Louis Park municipal well field to the north, St. Louis Park wells 1, 2 and 3 should also be abandoned.

3. The potential impact of the identified high concentrations of coal-tar derivatives in the glacial drift ground water are significant enough that mitigative measures are recommended to halt the movement of these wastes.

4. The control of ground water gradients in the glacial drift ground water system is technically feasible and the system presented in this report or a similar system should be implemented. It is recommended that design of the gradient control wells begin immediately. The first step in the design will be to place the additional wells and borings needed to define the exact location of gradient control wells. The next step will be to place one or more test wells to verify the aquifer characteristics needed to complete the design. The third step will be to complete the design and construct the wells.

5. Water pumped from the gradient control wells should be discharged to the sanitary sewer, at least initially. After the more highly contaminated ground water has been removed from the glacial drift or after treatability of the waste has been better defined, it may be possible to discharge the effluent from the wells to Minnehaha Creek after appropriate treatment.

6. Bench scale and pilot scale studies should be conducted to define the treatability of the ground water using either the existing surface water treatment facility or a new treatment concept.

7. The effectiveness of the gradient control system should be monitored both in terms of the ability of the wells to capture coal-tar derivatives through the glacial drift and Platteville limestone and, if the effluent is discharged to Minnehaha Creek, the ability of the treatment facility to meet effluent limitations prior to discharge.

8. Two additional wells should be placed in the St. Peter formation beneath the area of elevated coal-tar derivative at the drift/Platteville contact to monitor the quality of water in the St. Peter. If the average concentration of the phenolics, as measured by the MBTH Method, exceeds a concentration on the order of 20 micrograms per liter, significant change will have occurred and gradient control or some other appropriate mitigative measure should be required to control movement of the wastes in the St. Peter.

9. Further information is needed regarding the effect of the trace phenolic concentrations measured in the municipal wells in St. Louis Park. It is recommended that studies be carried out to define the potential public health effect of these trace phenolics.

10. A better definition of hydrogeology is needed in the buried bedrock valley located near Highway 100 and Excelsior Boulevard. Specifically, soil borings and piezometers should be placed in the valley to define its extent and to estimate gradients and likely vertical flow rates. In addition, monitoring wells should be placed near the western edge of the valley to define the quality of water discharged to the valley from the site area through the glacial drift, Platteville and St. Peter units. A monitoring well should also be placed in the St. Peter north of the valley to monitor the quality of the water in the aquifer between the valley and the City well field to the north.

* effect of dilution

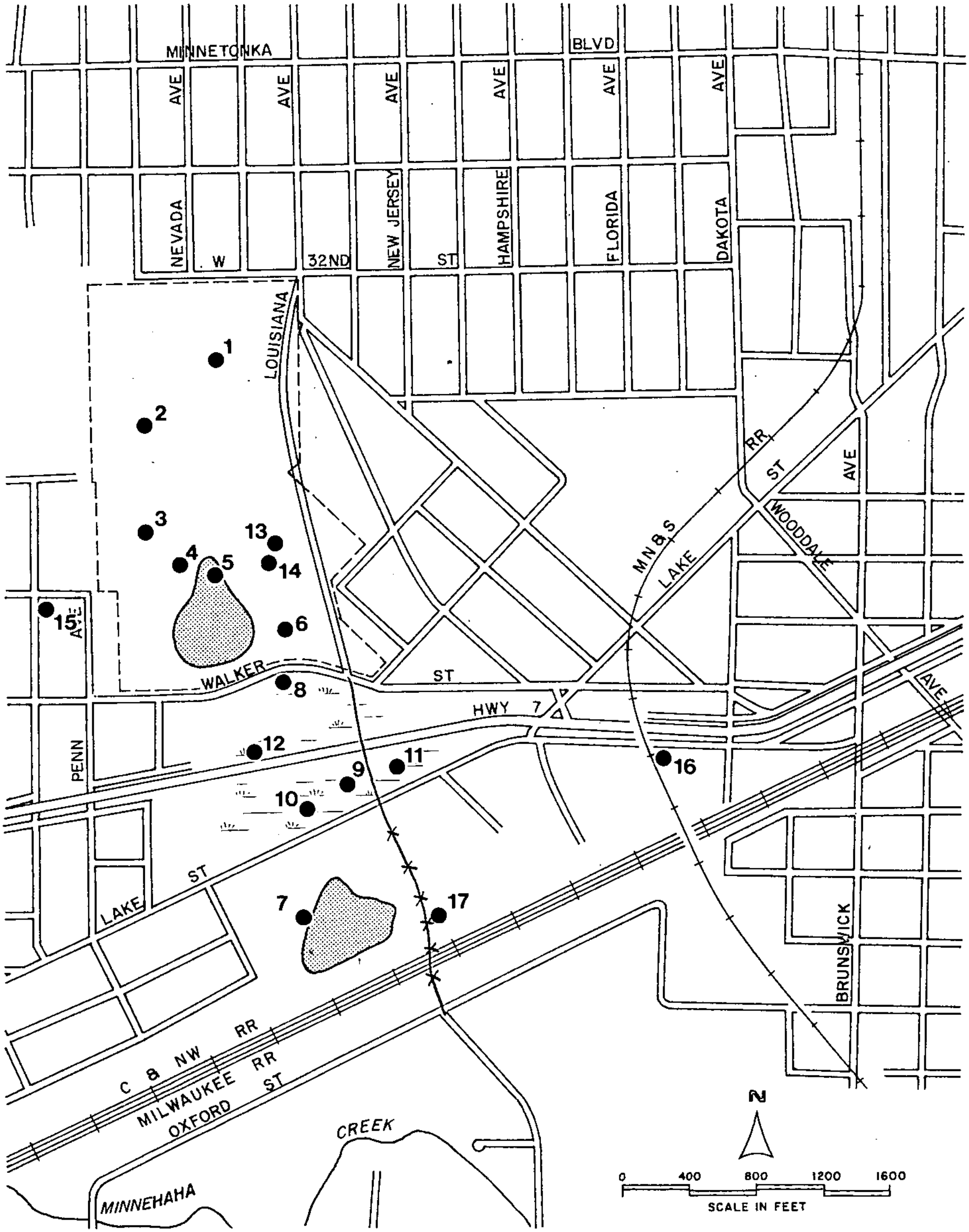
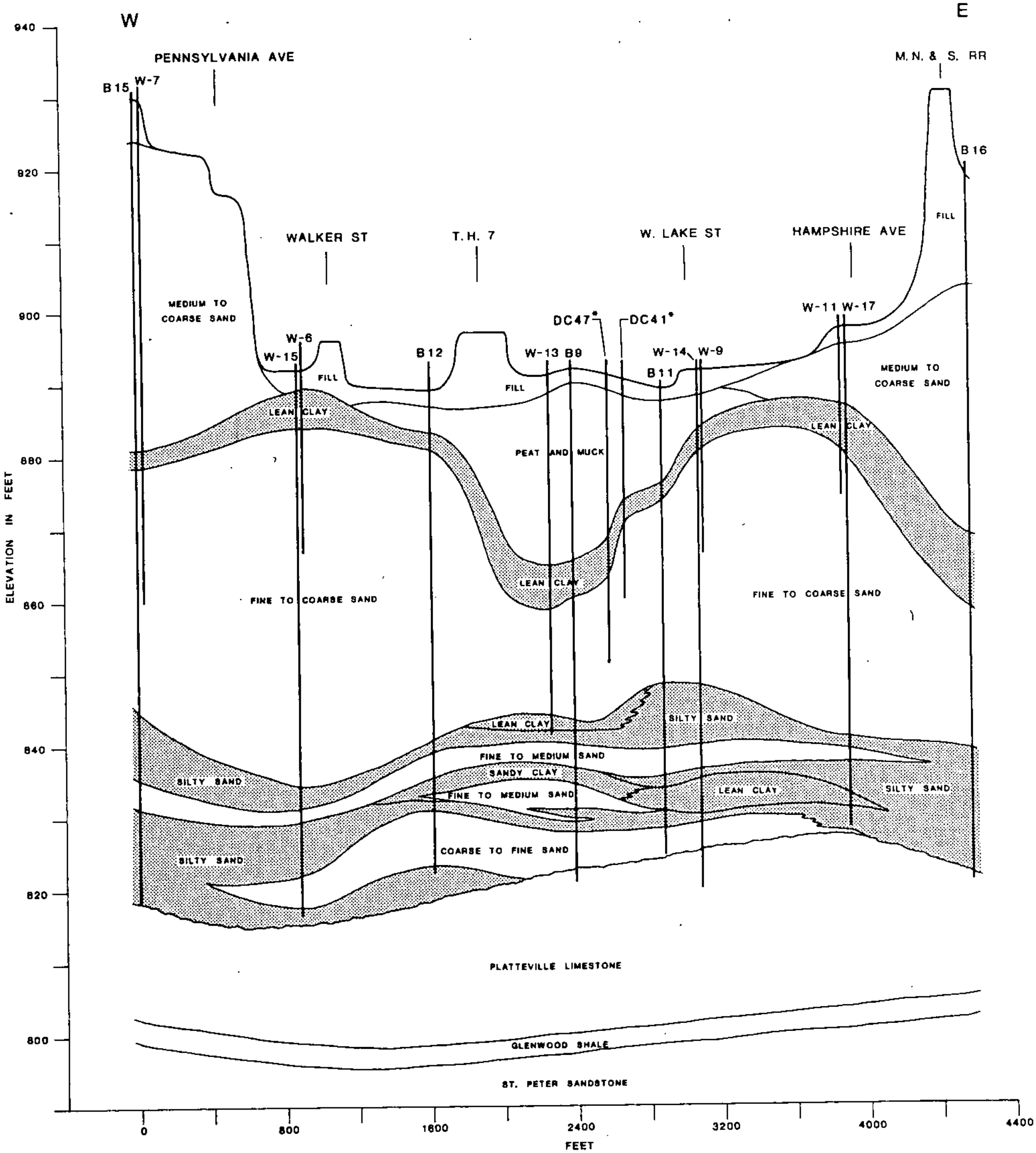


FIGURE 1

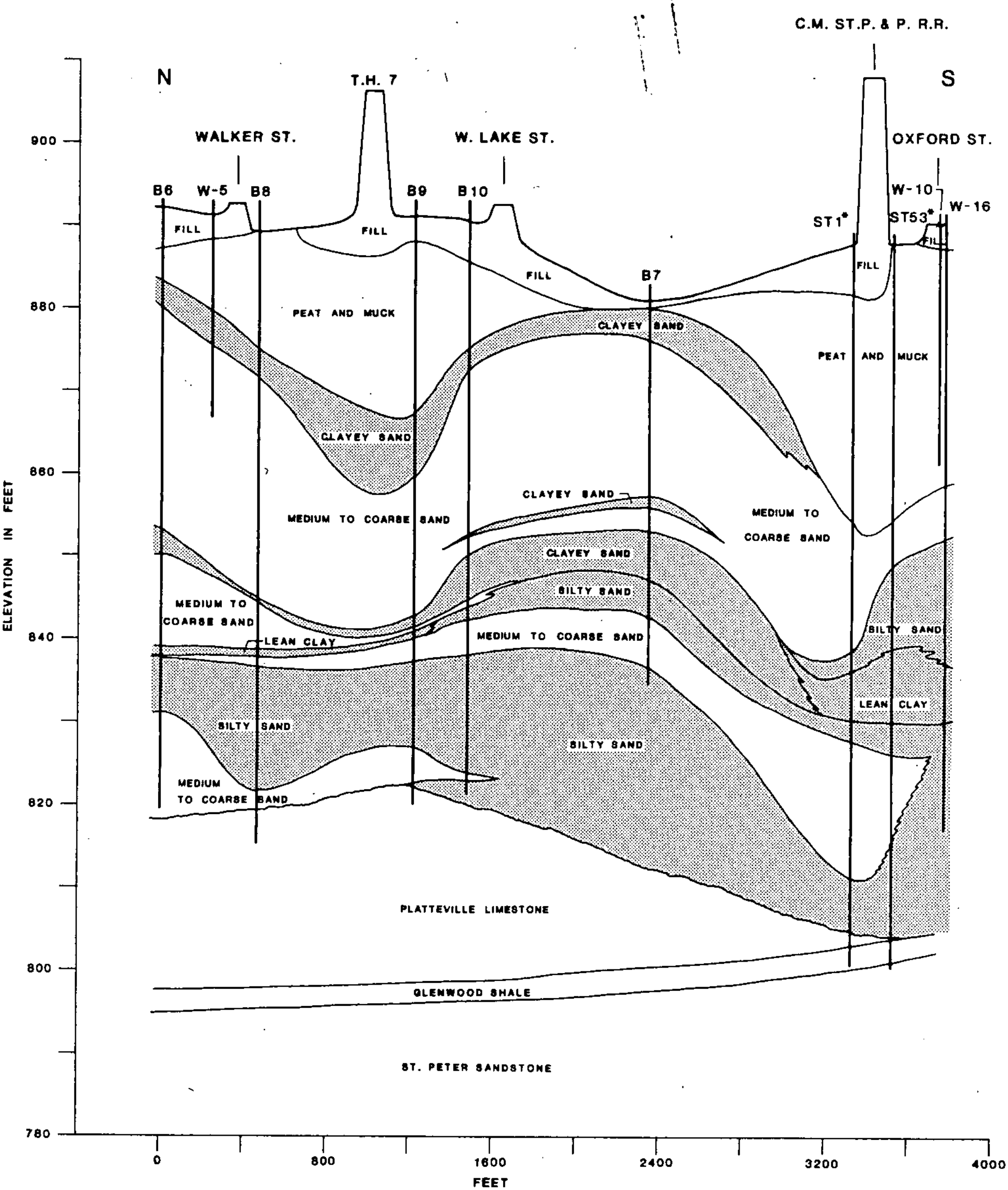
LOCATION OF SOIL BORINGS PLACED FOR THIS STUDY



*BORINGS BY BRAUN ENGINEERING TESTING PROJECT 71-63 LOUISIANA AVE. EXTENTION

FIGURE 2

EAST-WEST STRATIGRAPHIC CROSS-SECTION
THROUGH STUDY AREA



*BORINGS BY BRAUN ENGINEERING TESTING PROJECT 71-63 LOUISIANA AVE. EXTENTION

FIGURE 3

NORTH-SOUTH STRATIGRAPHIC CROSS-SECTION THROUGH STUDY AREA

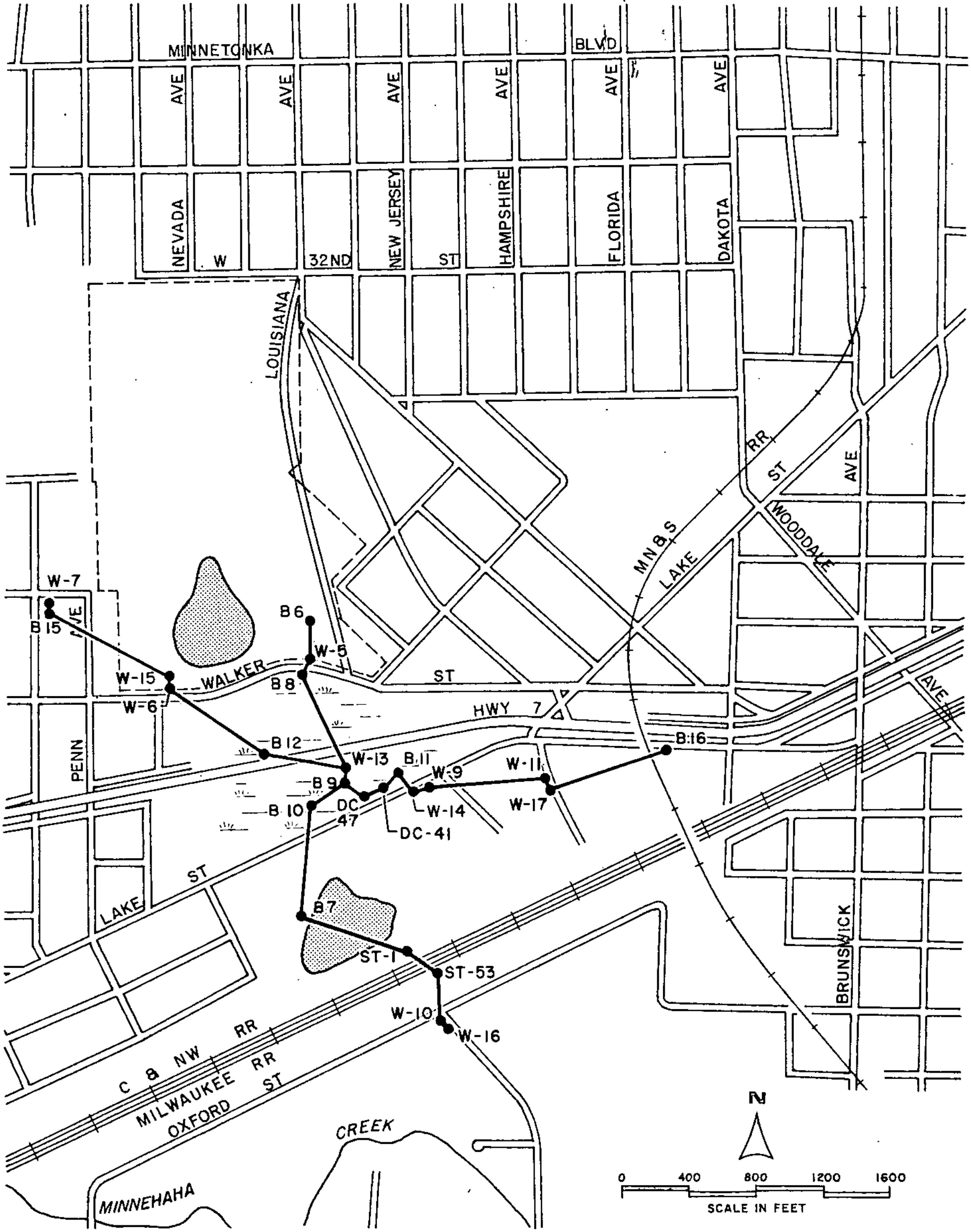


FIGURE 4

LOCATION OF STRATIGRAPHIC CROSS-SECTIONS

Program: ____________________________________

____

Date & Time: ________________ Register by: ______

NAME	Hike	Craft	TEL. NO

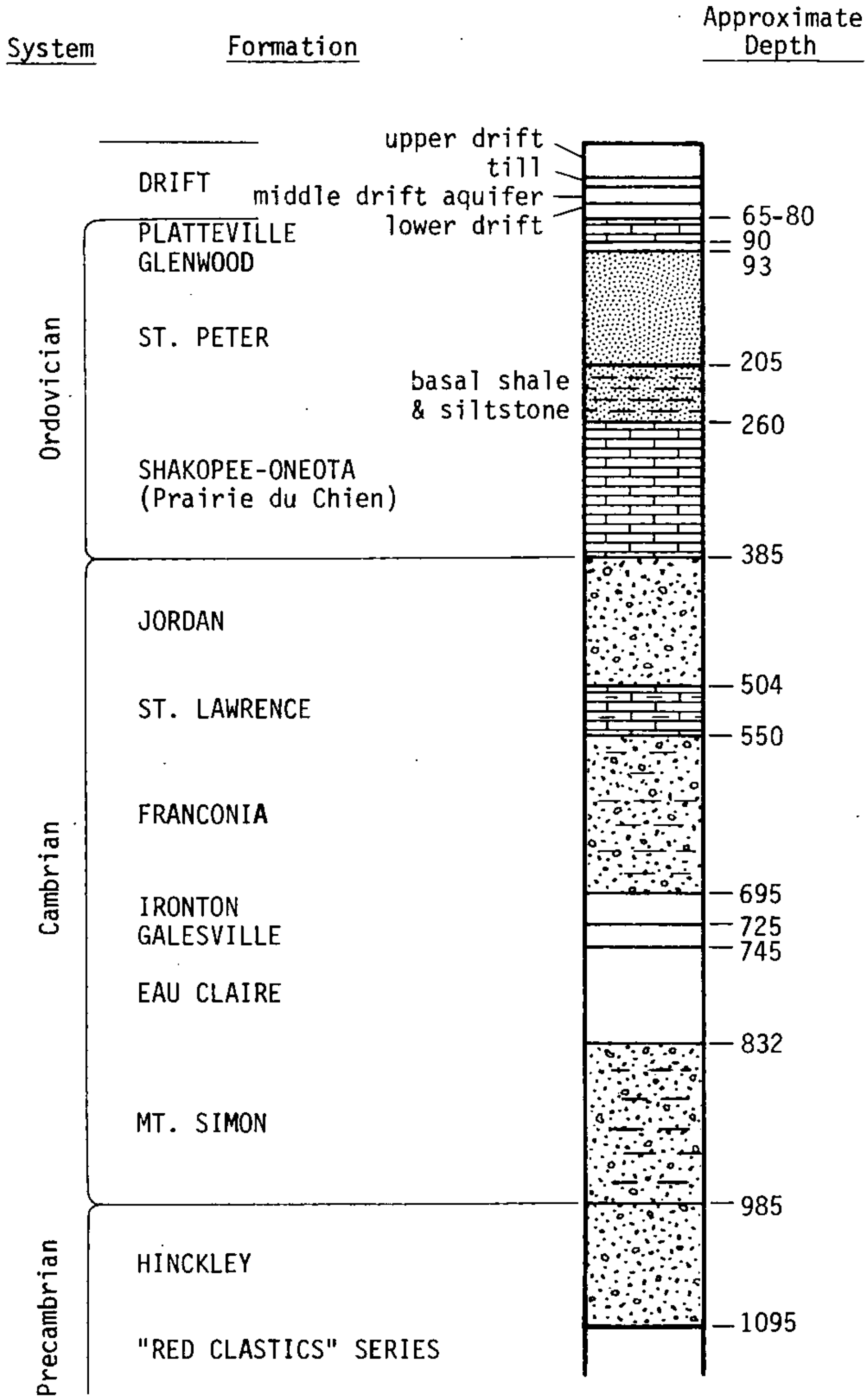


FIGURE 5

GENERALIZED GEOLOGIC COLUMN

Adopted from Sunde, Hydrogeologic Study of the Republic Creosote Site (1974).

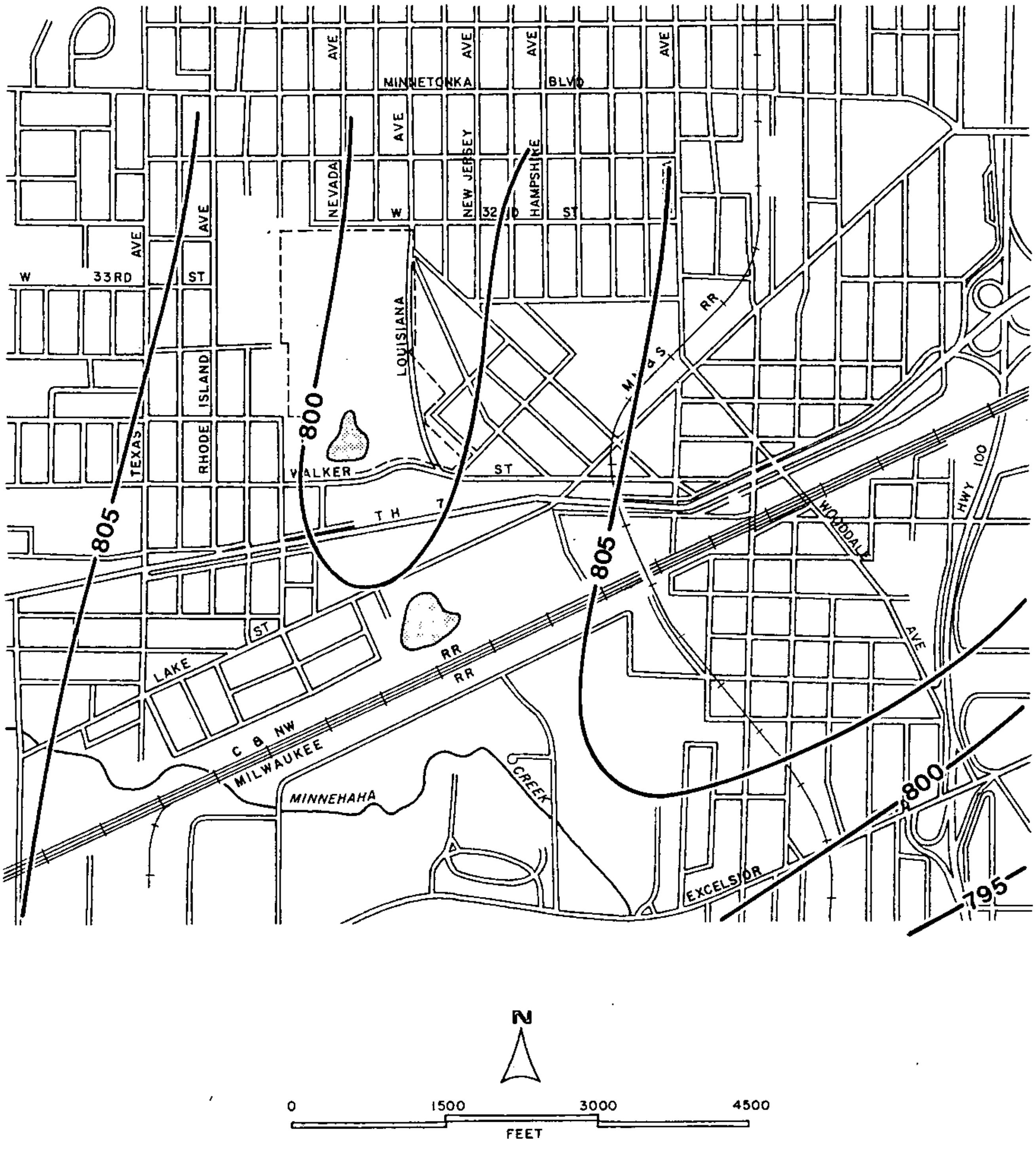


FIGURE 6

ELEVATION OF THE PLATTEVILLE-GLENWOOD CONTACT (MSL)

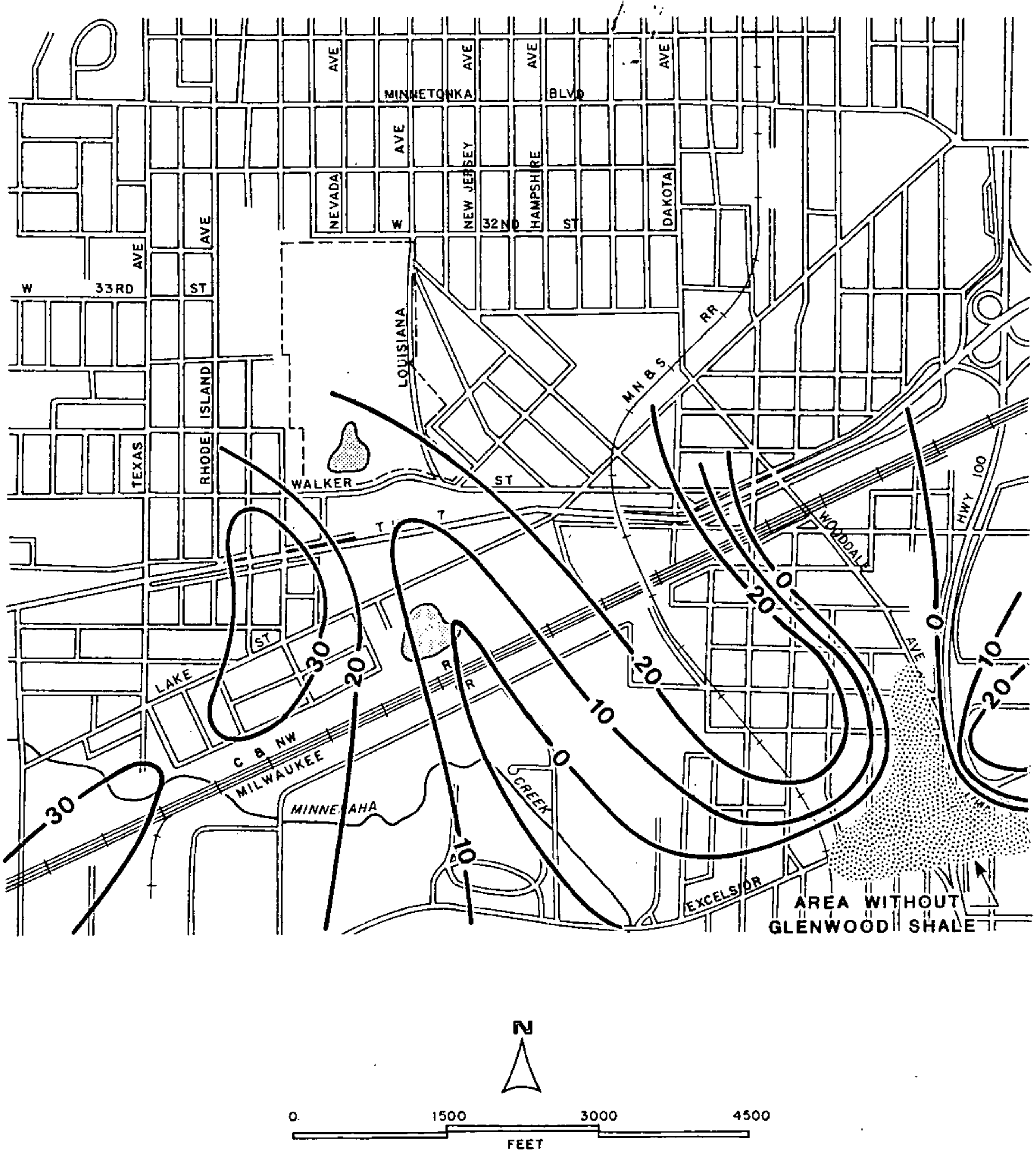


FIGURE 7

THICKNESS OF THE PLATTEVILLE LIMESTONE FORMATION (FEET)

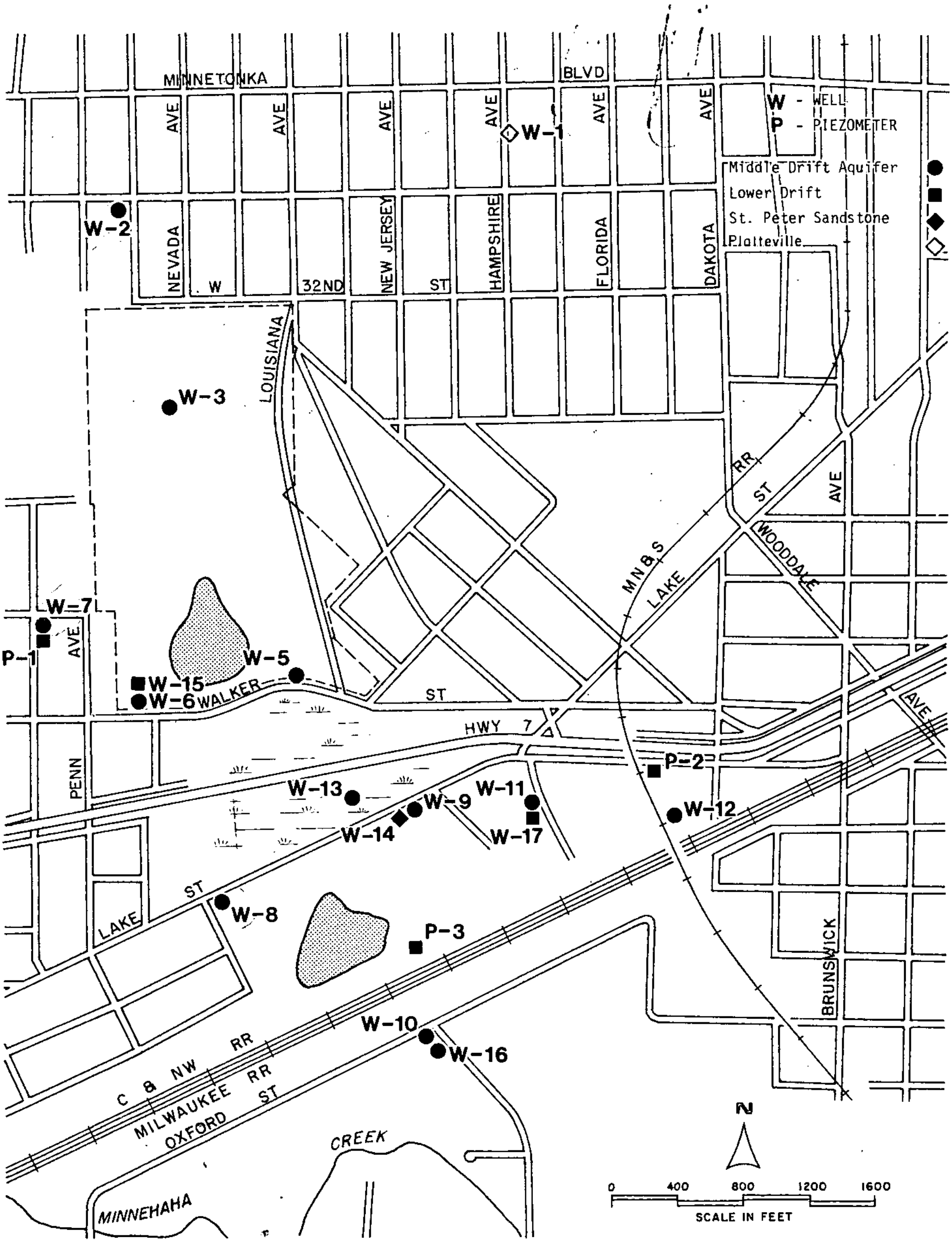


FIGURE 8

LOCATION OF MONITORING WELLS PLACED FOR THIS STUDY

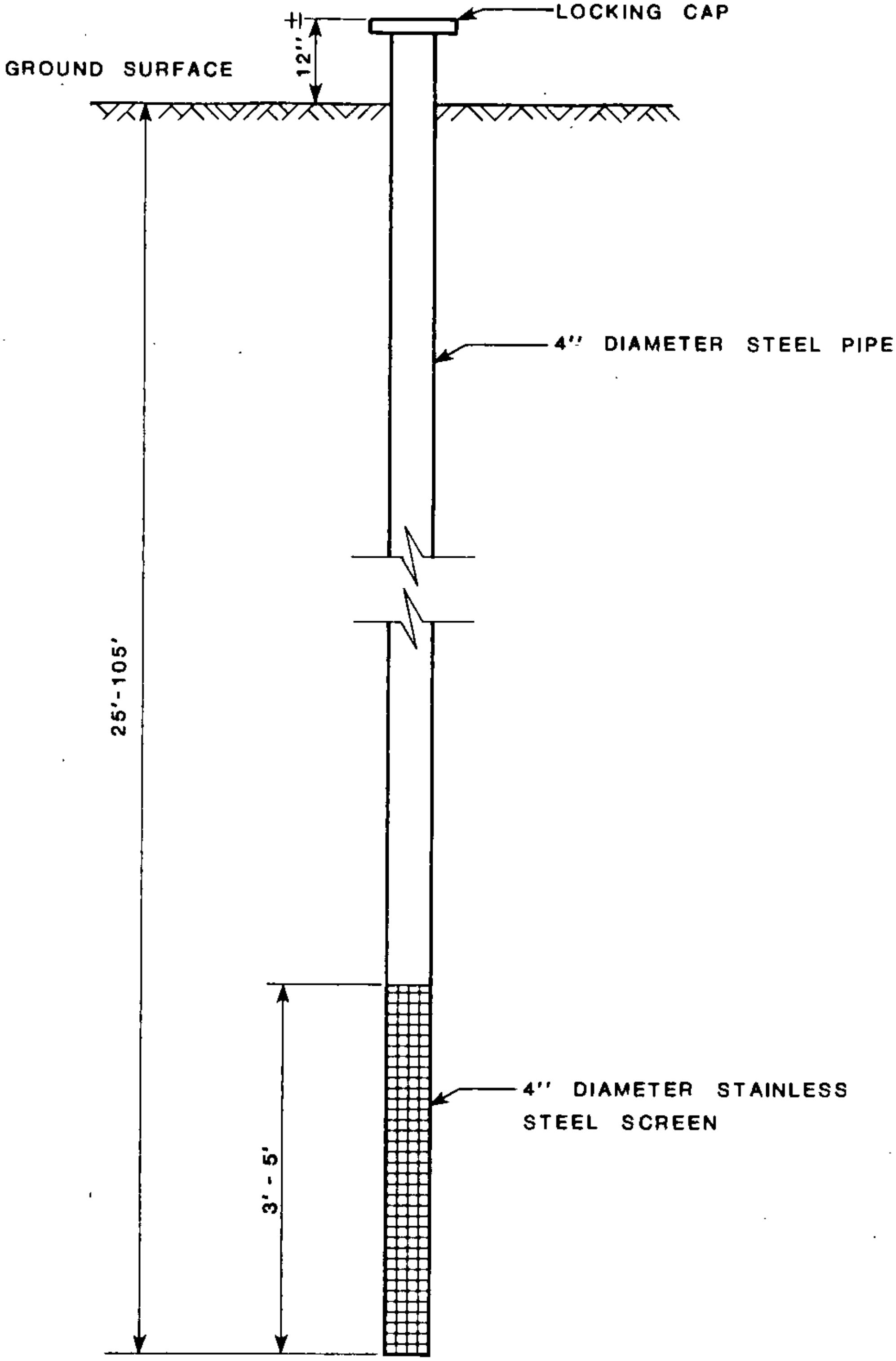


FIGURE 9
SECTION THROUGH TYPICAL GLACIAL DRIFT MONITORING WELL

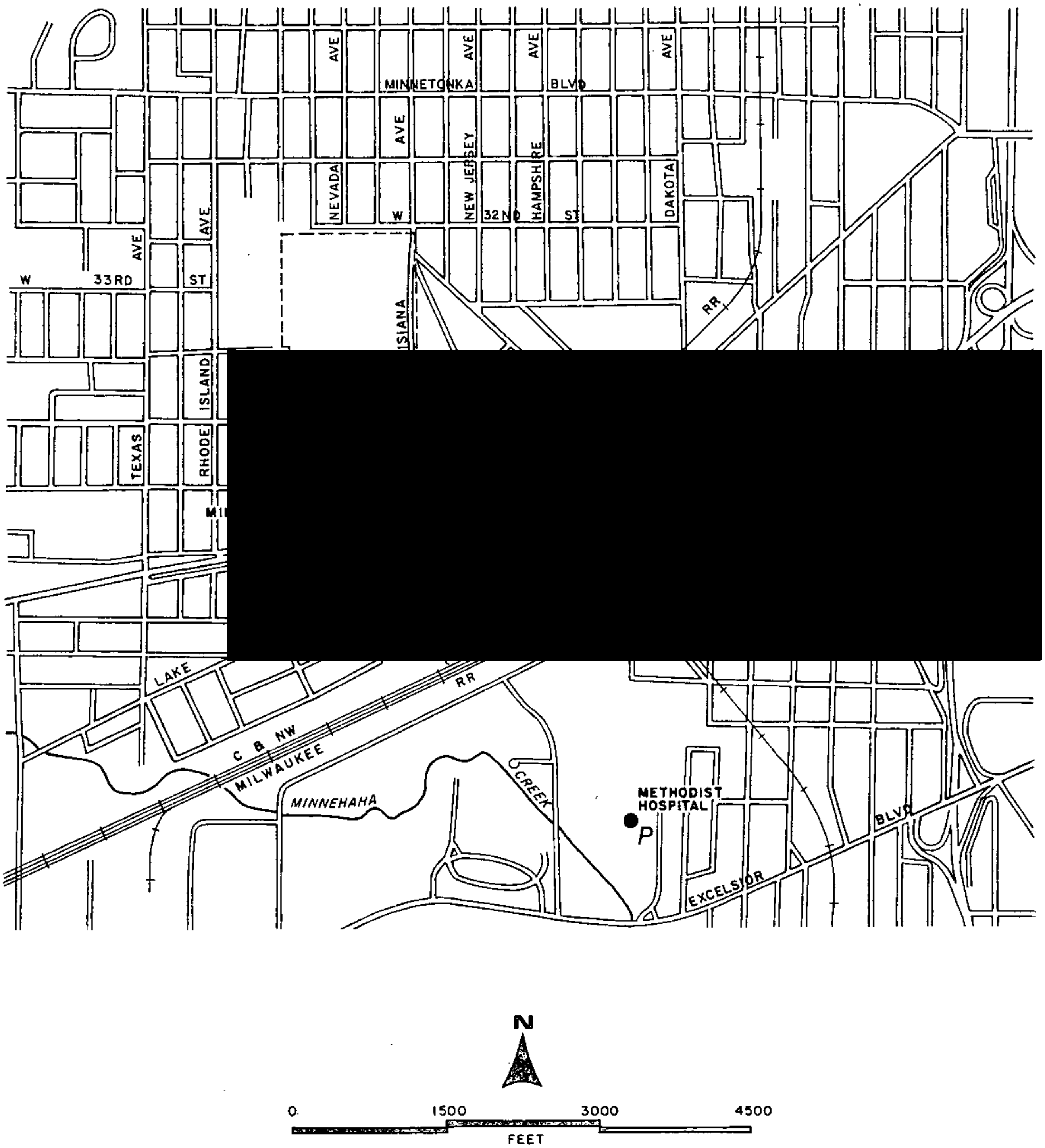


FIGURE 10

PRIVATE WELLS LOCATED IN THE FIELD DURING THIS STUDY

D - Glacial Drift
PL - Platteville
S - St. Peter
P - Prairie du Chien-Jordan
H - Mt. Simon-Hinckley
U - Unknown

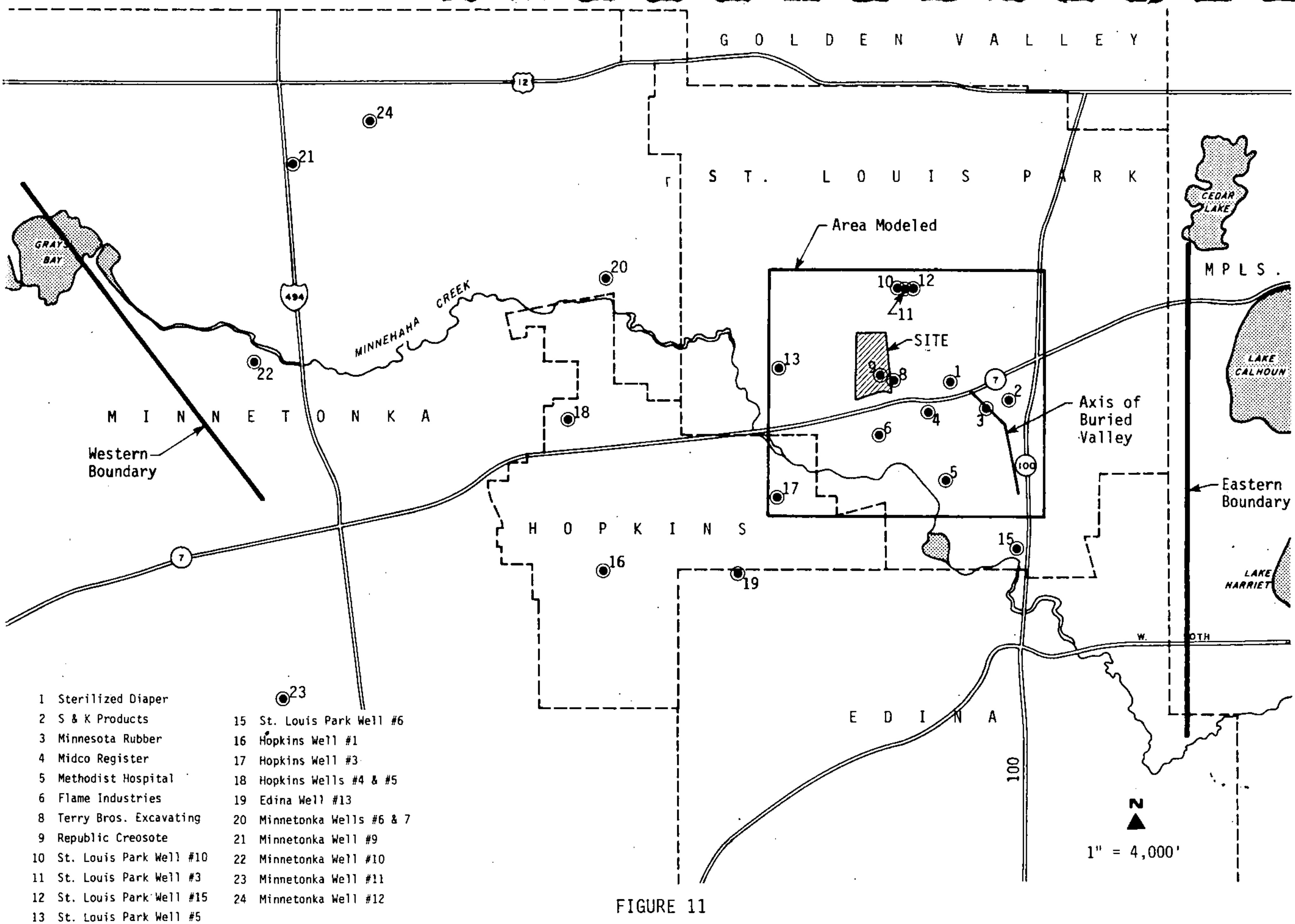


FIGURE 11

BOUNDARY CONDITIONS USED IN MODELING OF
ST. PETER-PRAIRIE DU CHIEN AQUIFERS

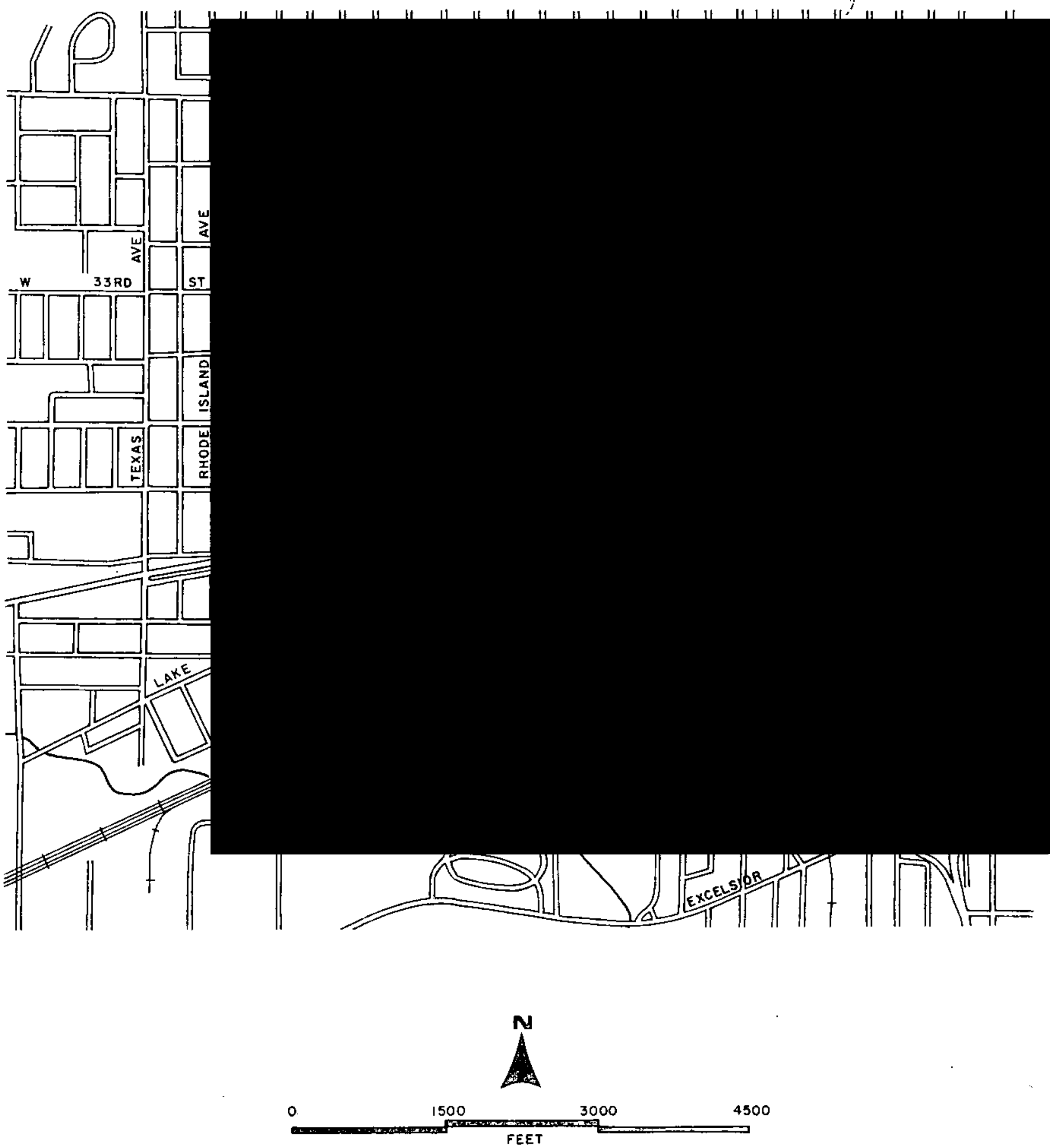


FIGURE 12

MUNICIPAL, INDUSTRIAL AND PRIVATE
WELLS SAMPLED DURING THIS STUDY

● - Glacial Drift
△ - Platteville
▲ - St. Peter
□ - Prairie du Chien-Jordan
■ - Mt. Simon-Hinckley

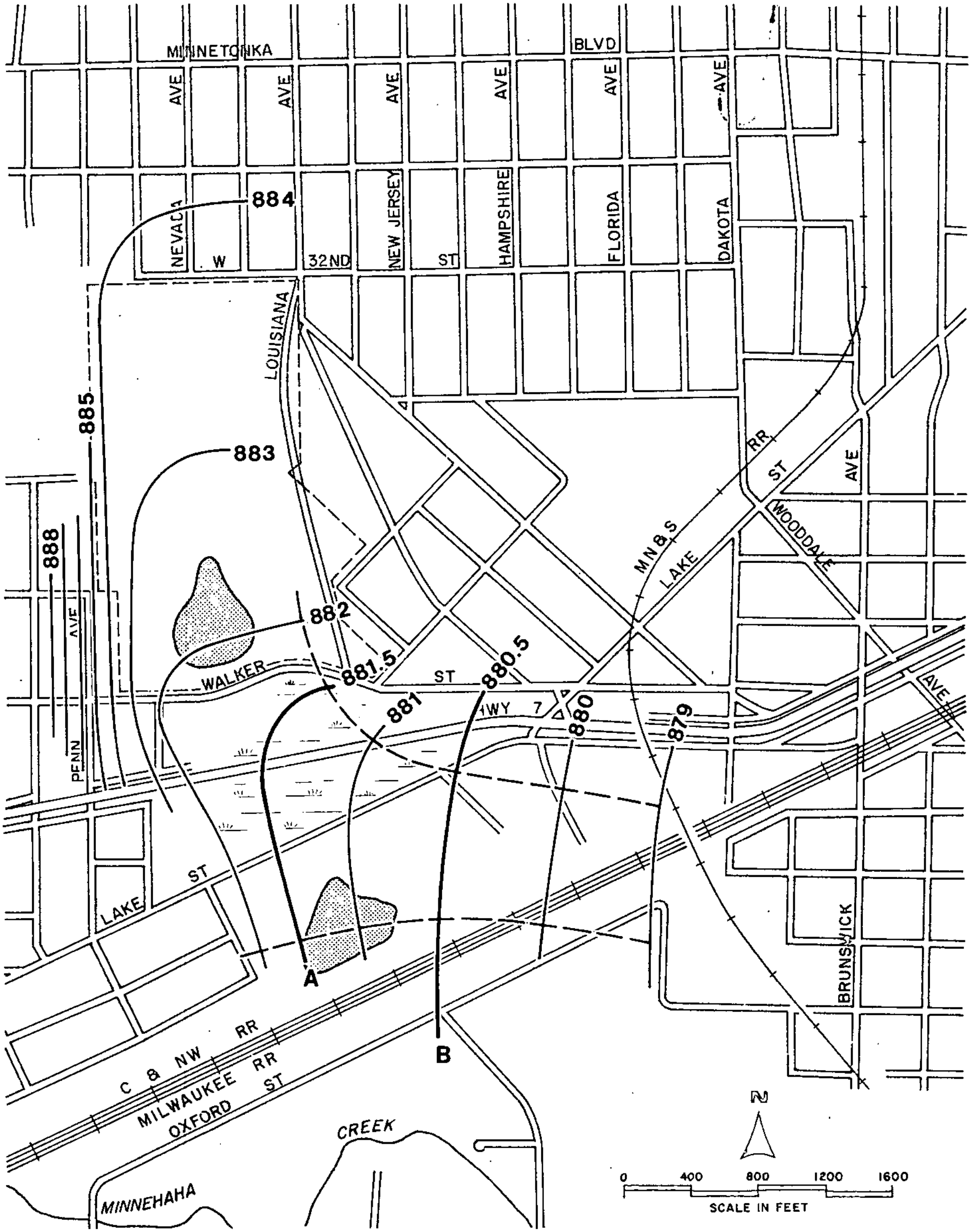


FIGURE 13

PIEZOMETRIC CONTOURS (MSL)--MIDDLE
DRIFT AQUIFER--WINTER, 1976-77

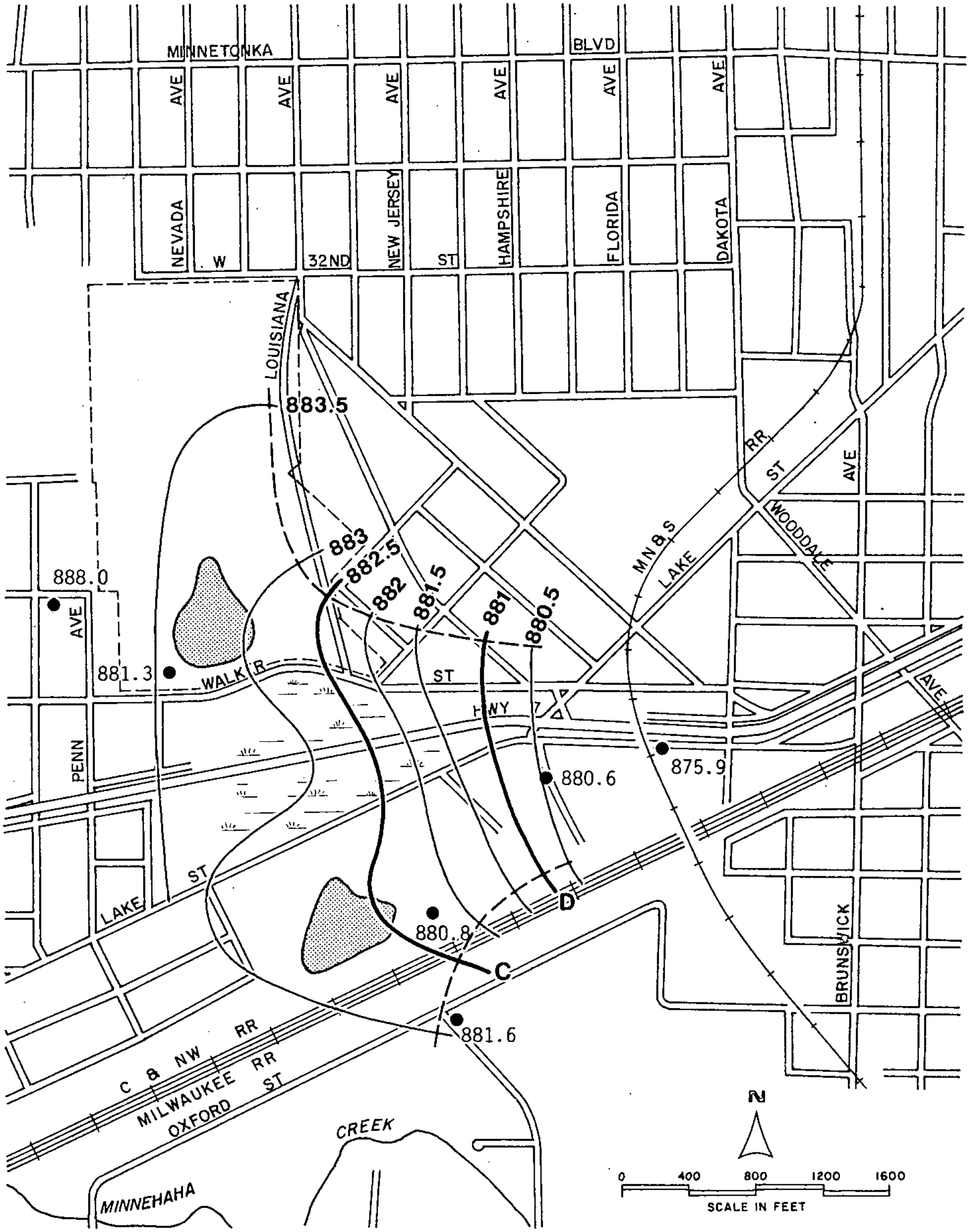


FIGURE 14

PIEZOMETRIC CONTOURS (MSL)--
MIDDLE DRIFT AQUIFER--JUNE 15, 1977

Piezometric level at drift/Platteville Contact ● 880.6

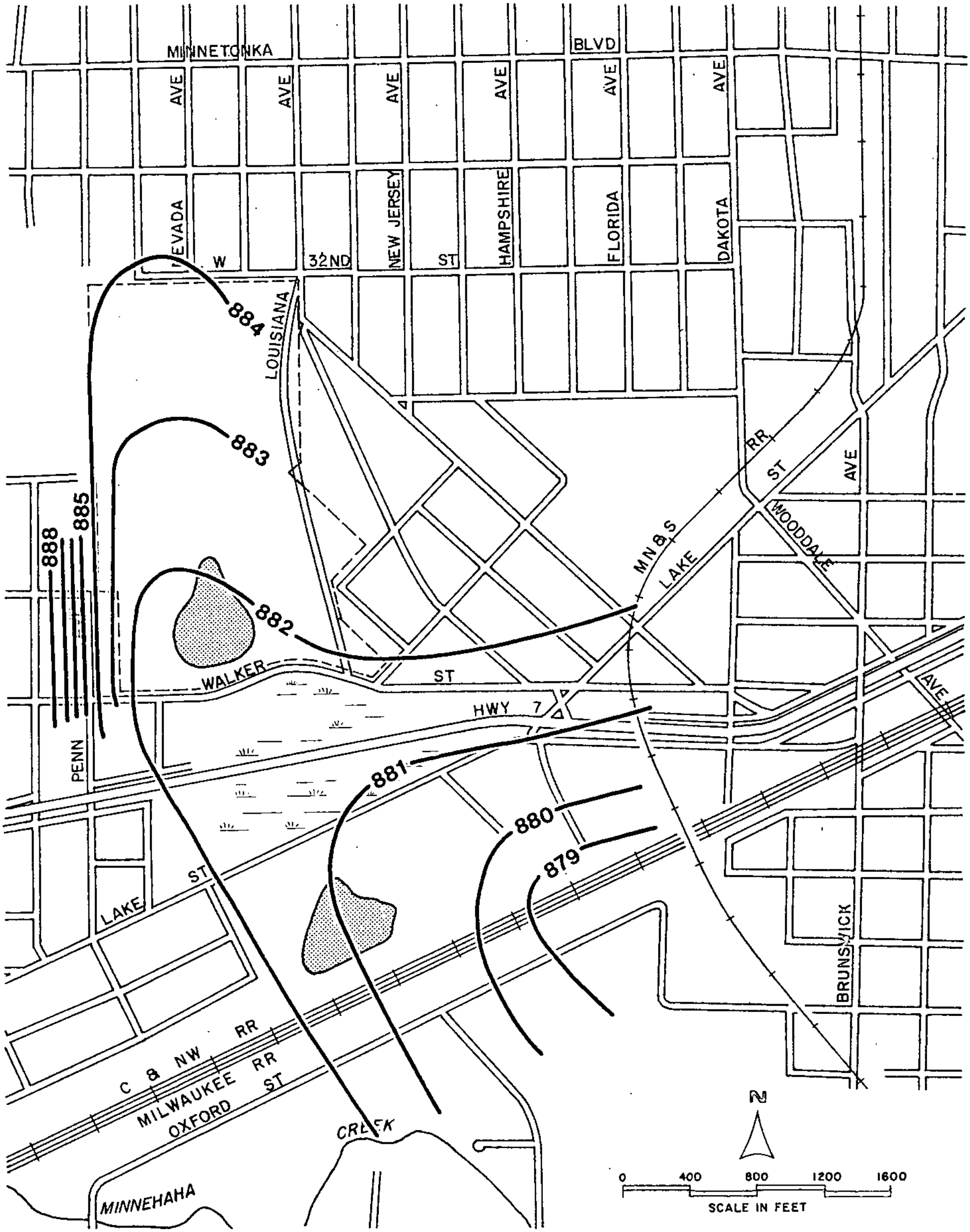


FIGURE 15

PIEZOMETRIC CONTOURS (MSL)--MIDDLE DRIFT AQUIFER--SECOND INTERPRETATION

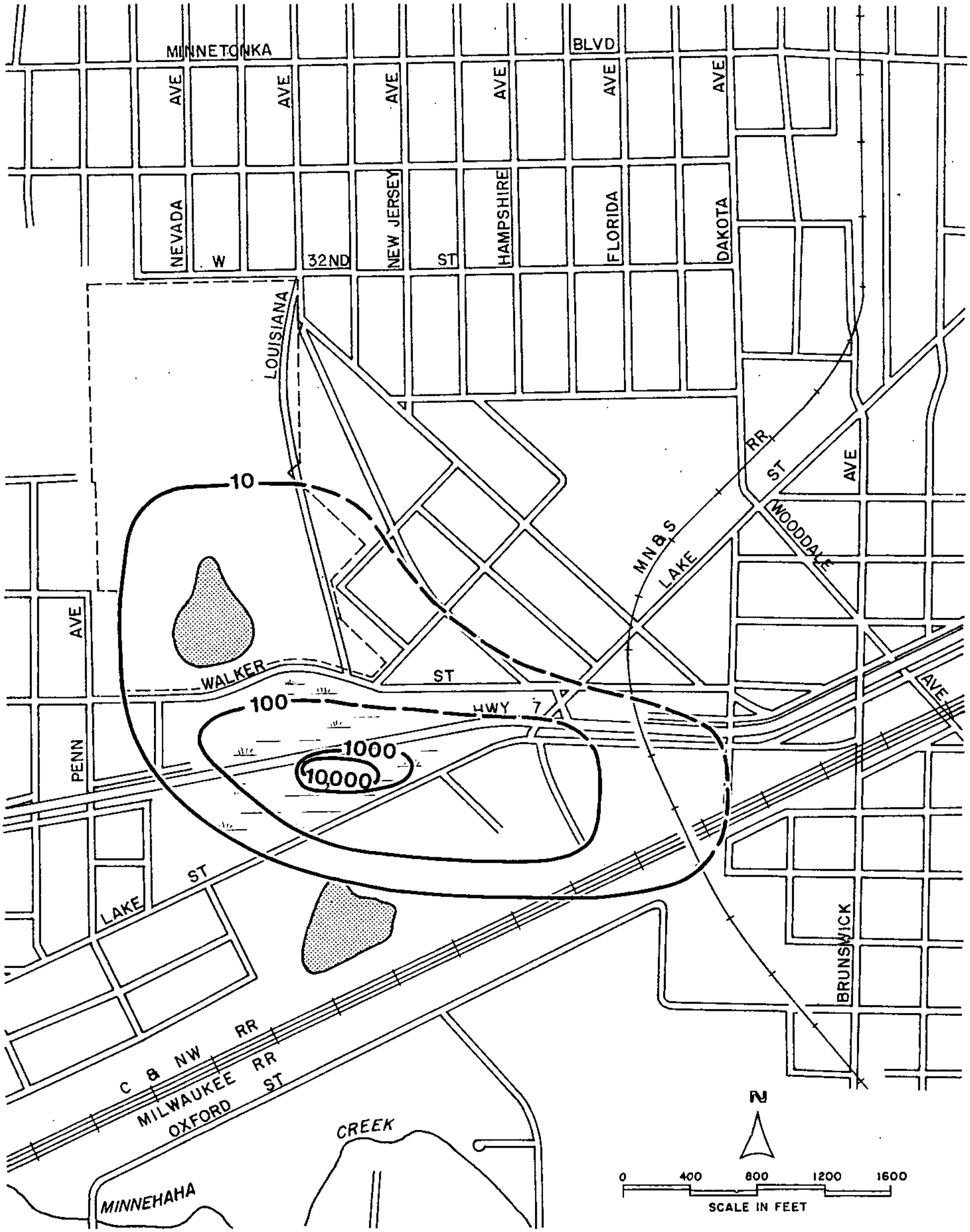


FIGURE 16

PHENOLIC CONCENTRATION CONTOURS--
GLACIAL DRIFT (μg/l)--FIRST INTERPRETATION

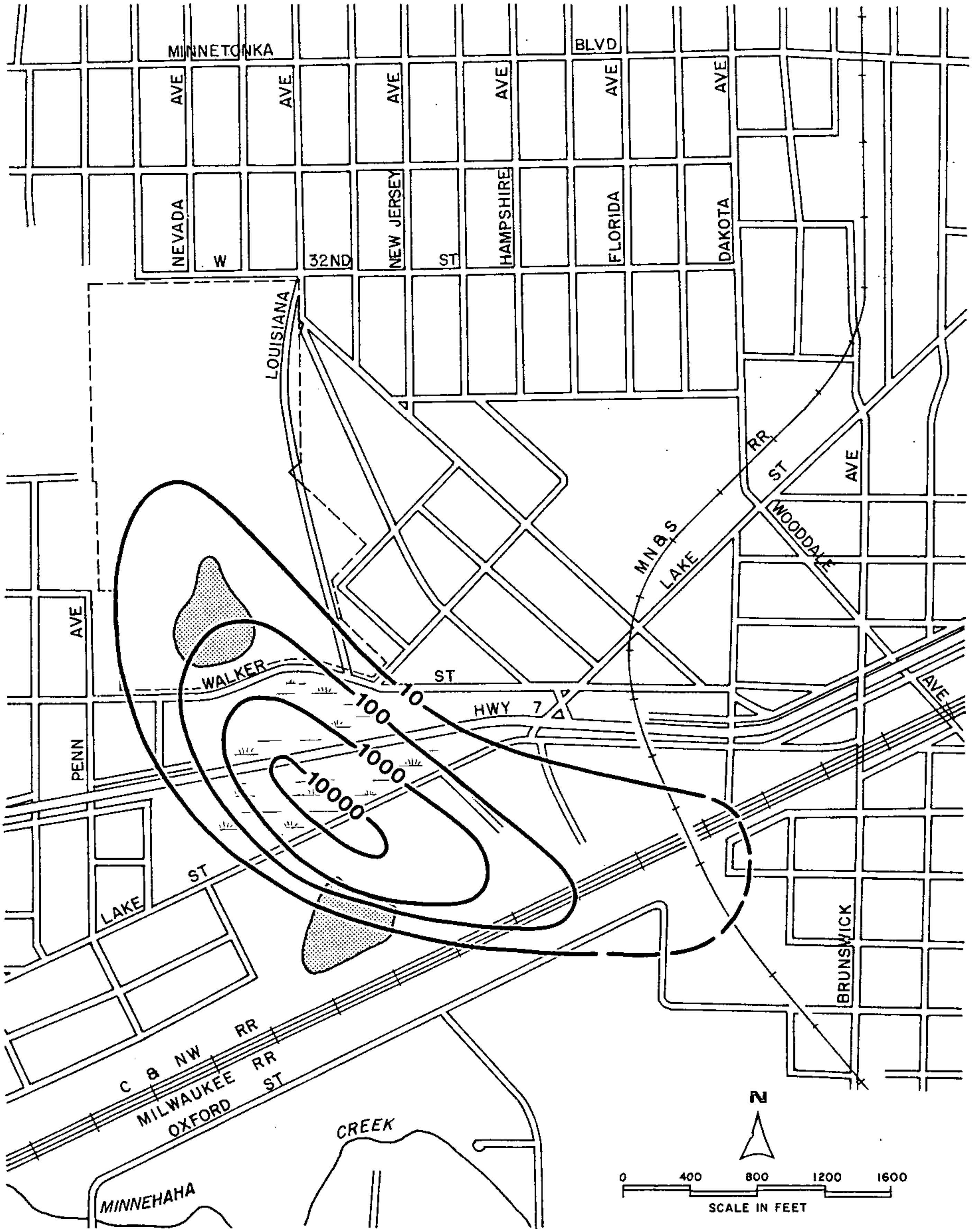


FIGURE 17

PHENOLIC CONCENTRATION CONTOURS--
GLACIAL DRIFT (μg/l)--SECOND INTERPRETATION

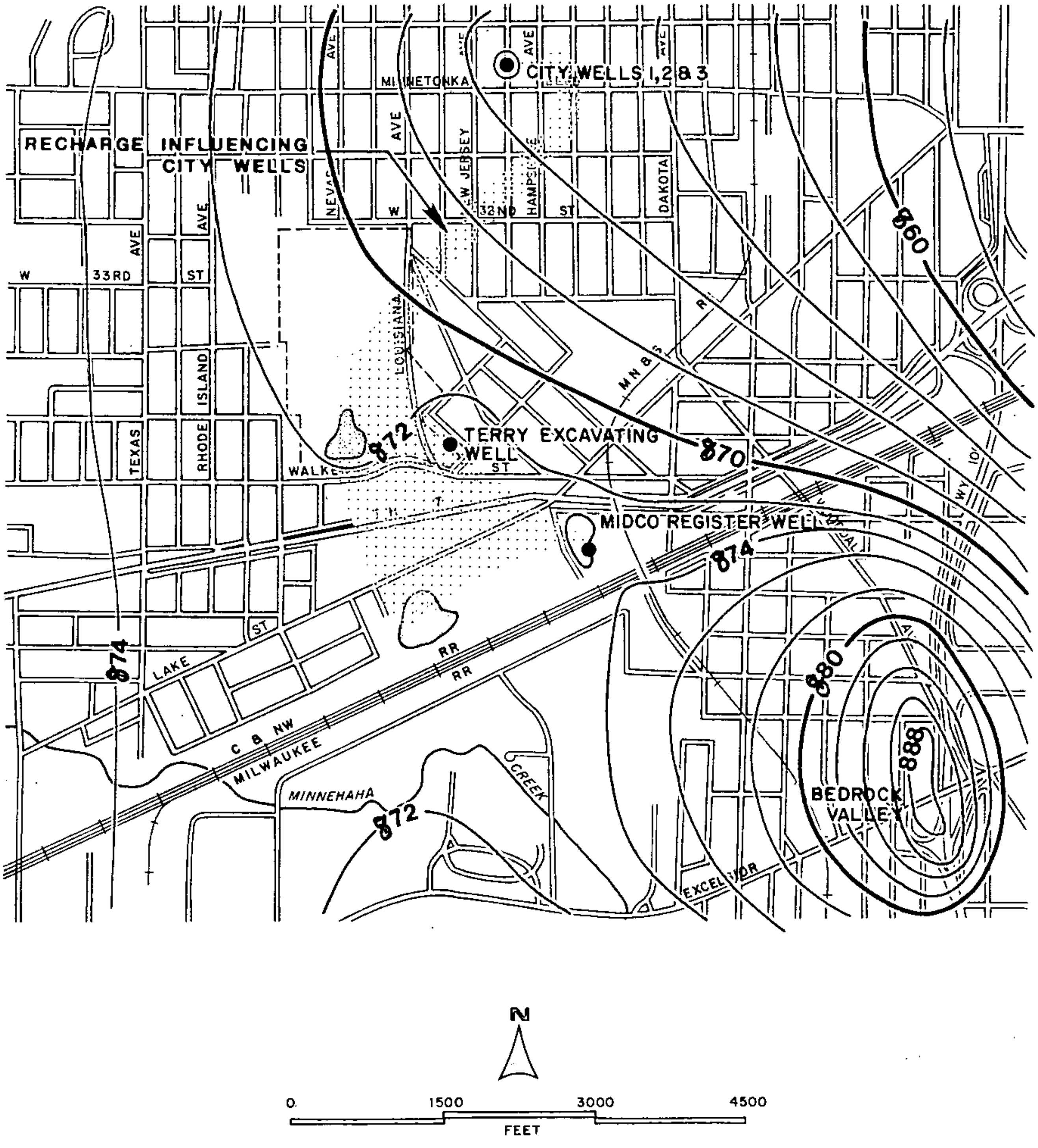


FIGURE 18

EXISTING PIEZOMETRIC LEVELS IN THE ST. PETER AQUIFER (MSL)--WINTER CONDITIONS

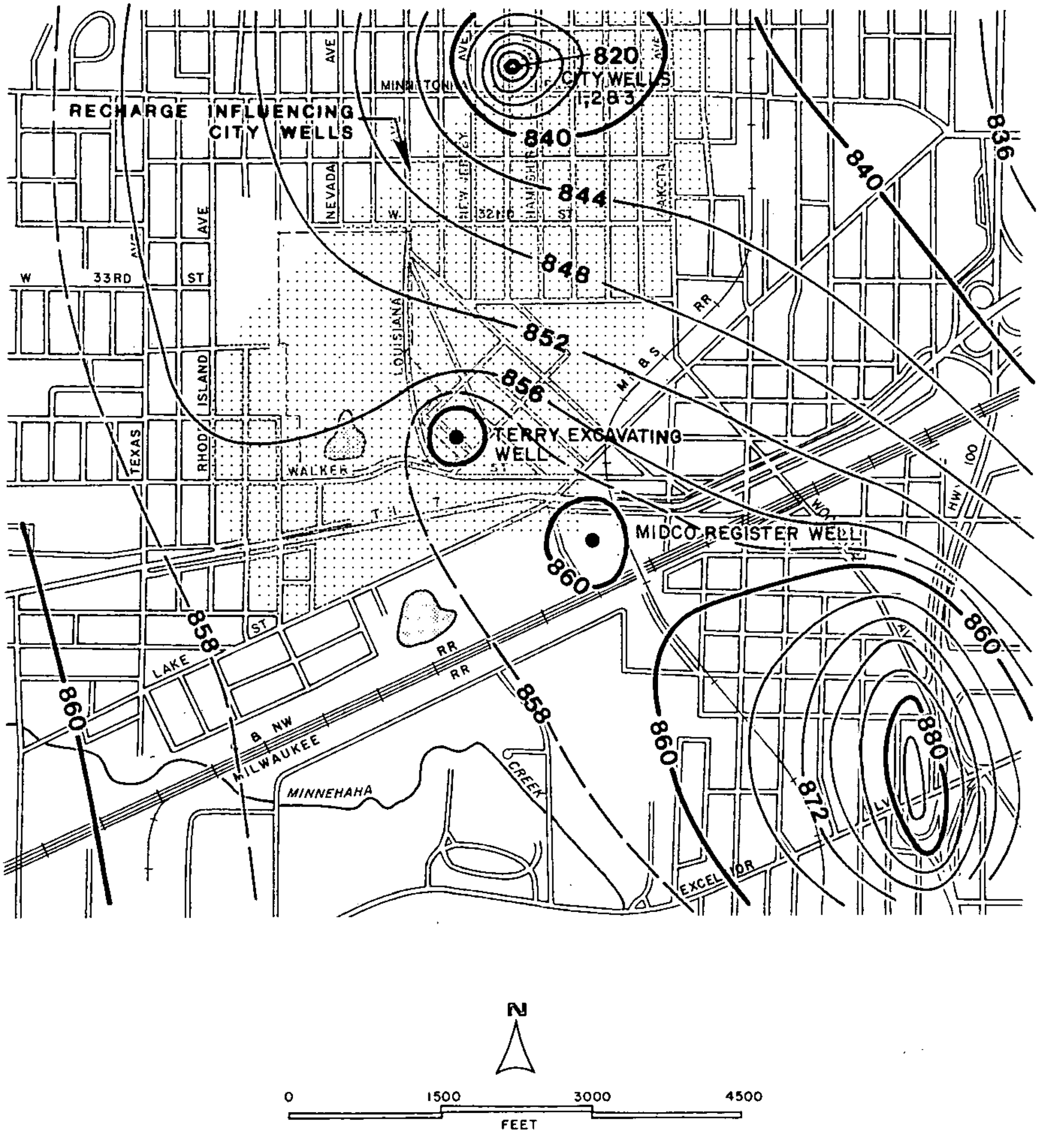


FIGURE 19

EXISTING PIEZOMETRIC LEVELS IN THE ST. PETER
AQUIFER (MSL)--SUMMER CONDITIONS

FIGURE 20

EXISTING PIEZOMETRIC LEVELS IN THE PRAIRIE DU CHIEN-JORDAN AQUIFER (MSL)--WINTER CONDITIONS

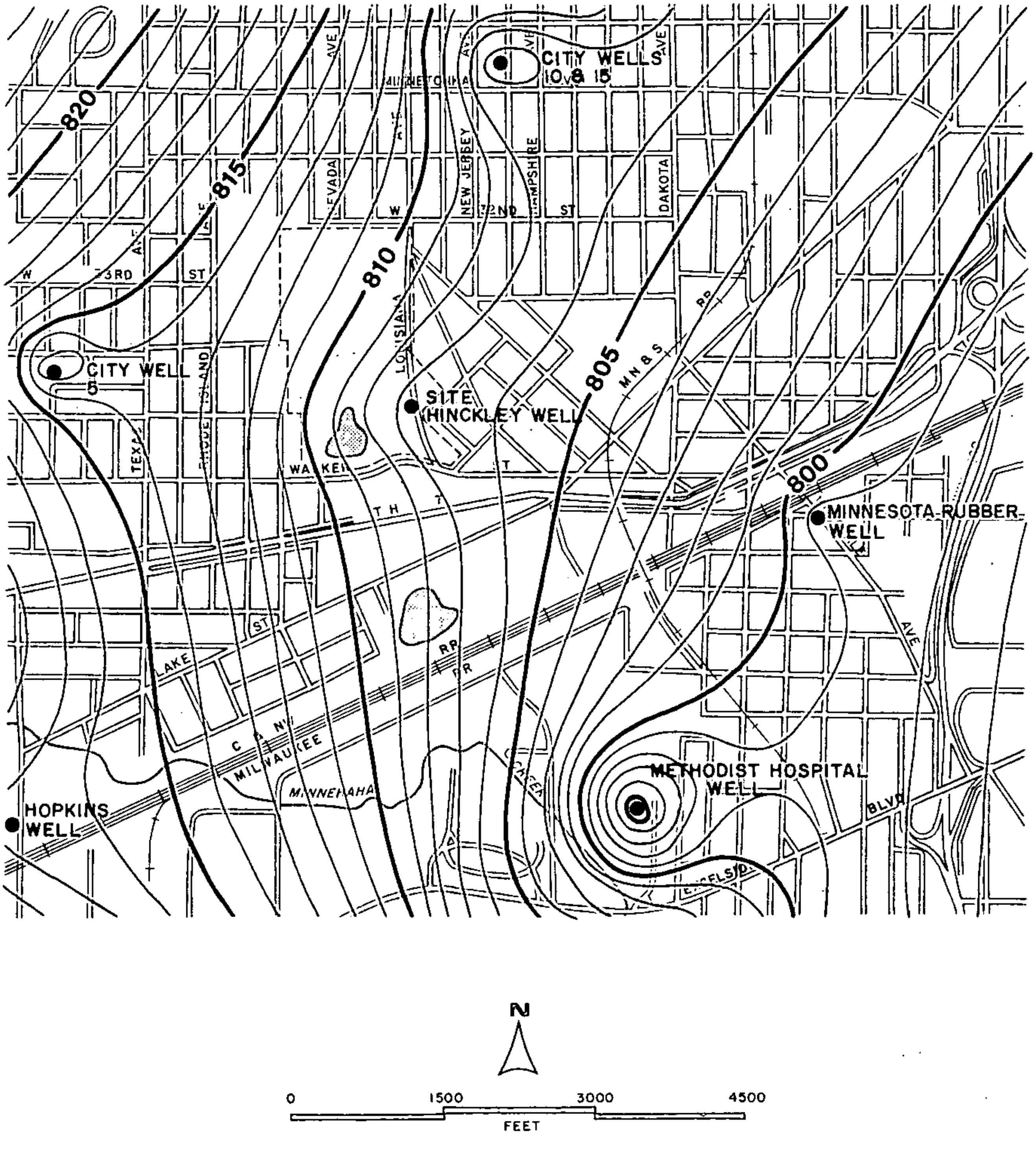


FIGURE 21

EXISTING PIEZOMETRIC LEVELS IN THE PRAIRIE DU CHIEN-
JORDAN AQUIFER (MSL)--SUMMER CONDITIONS

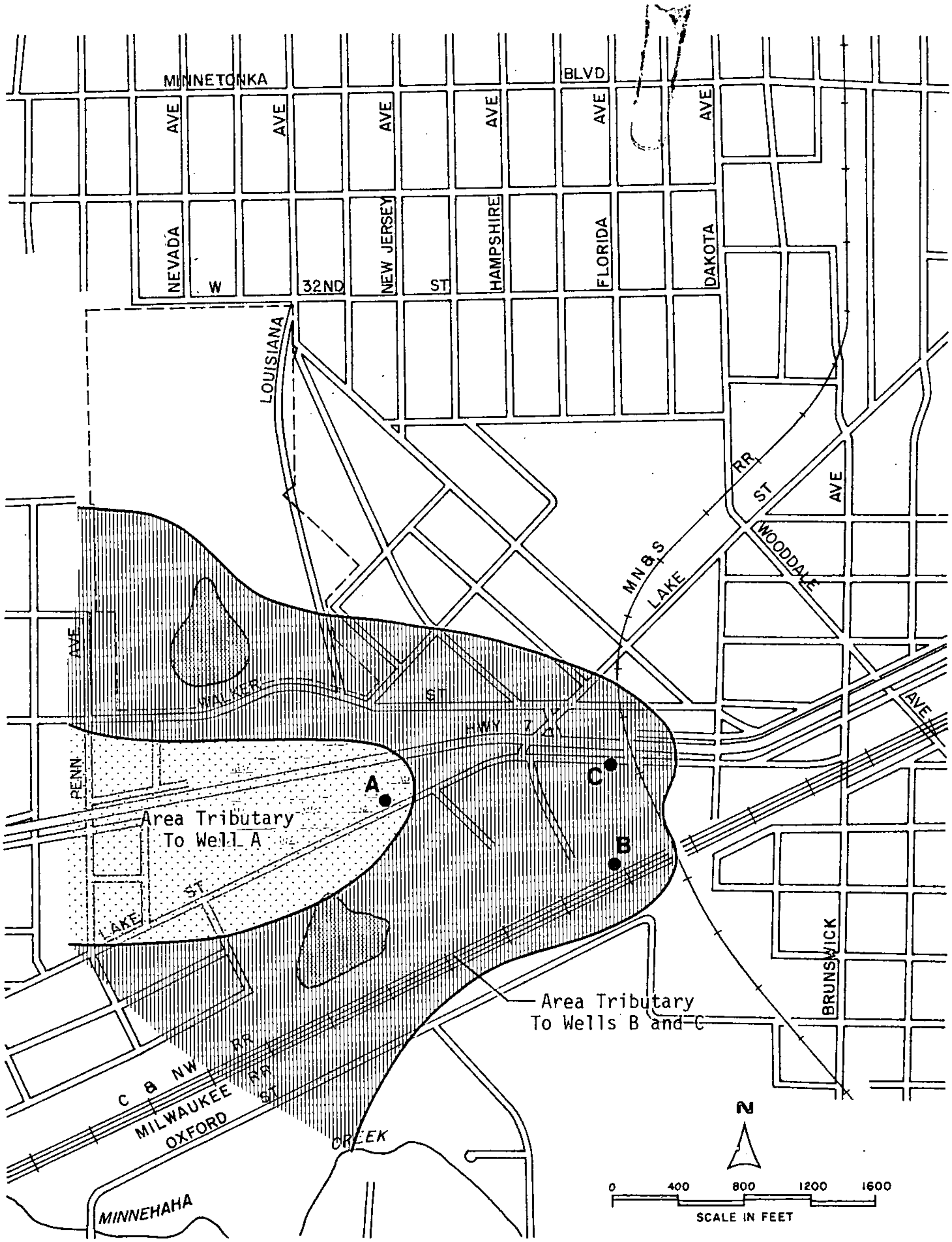


FIGURE 22

AREAS TRIBUTARY TO GRADIENT CONTROL WELLS

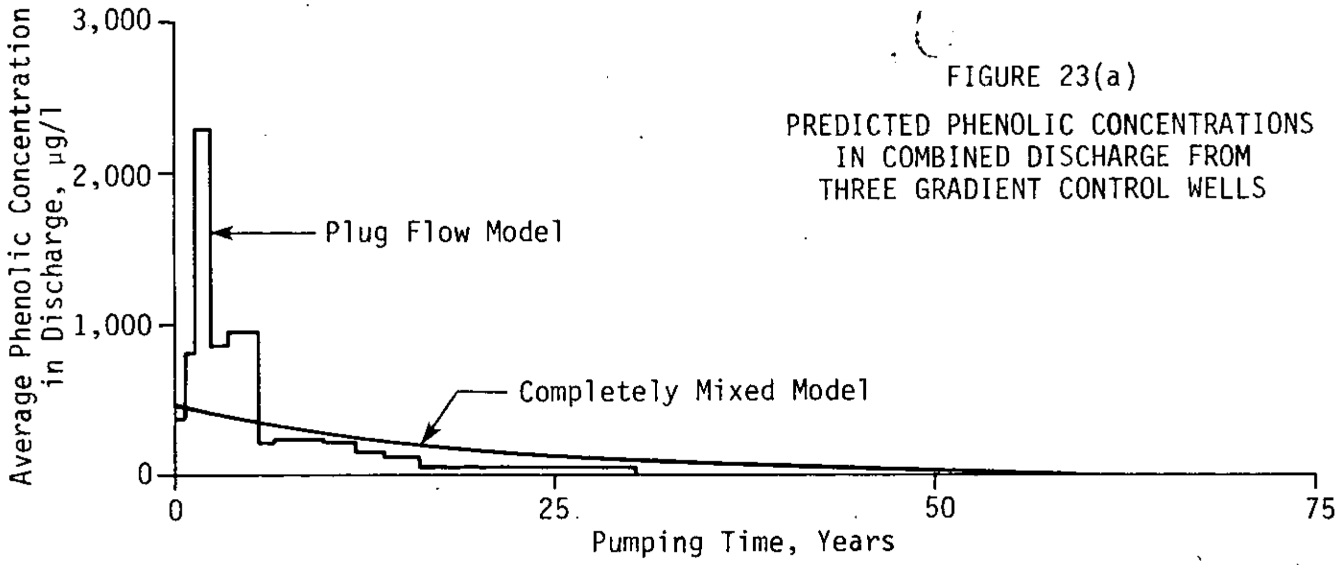


FIGURE 23(a)

PREDICTED PHENOLIC CONCENTRATIONS IN COMBINED DISCHARGE FROM THREE GRADIENT CONTROL WELLS

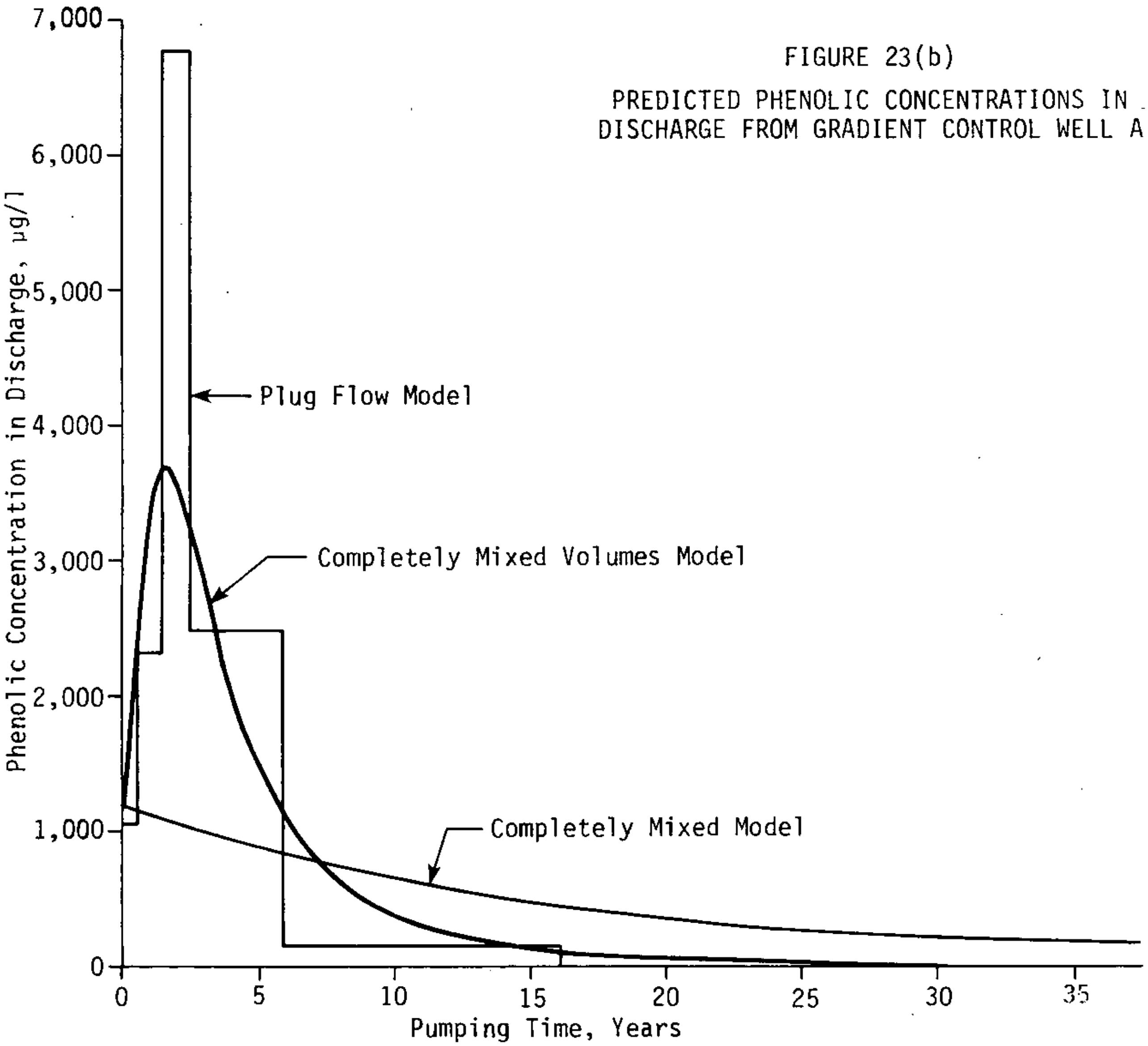


FIGURE 23(b)

PREDICTED PHENOLIC CONCENTRATIONS IN DISCHARGE FROM GRADIENT CONTROL WELL A

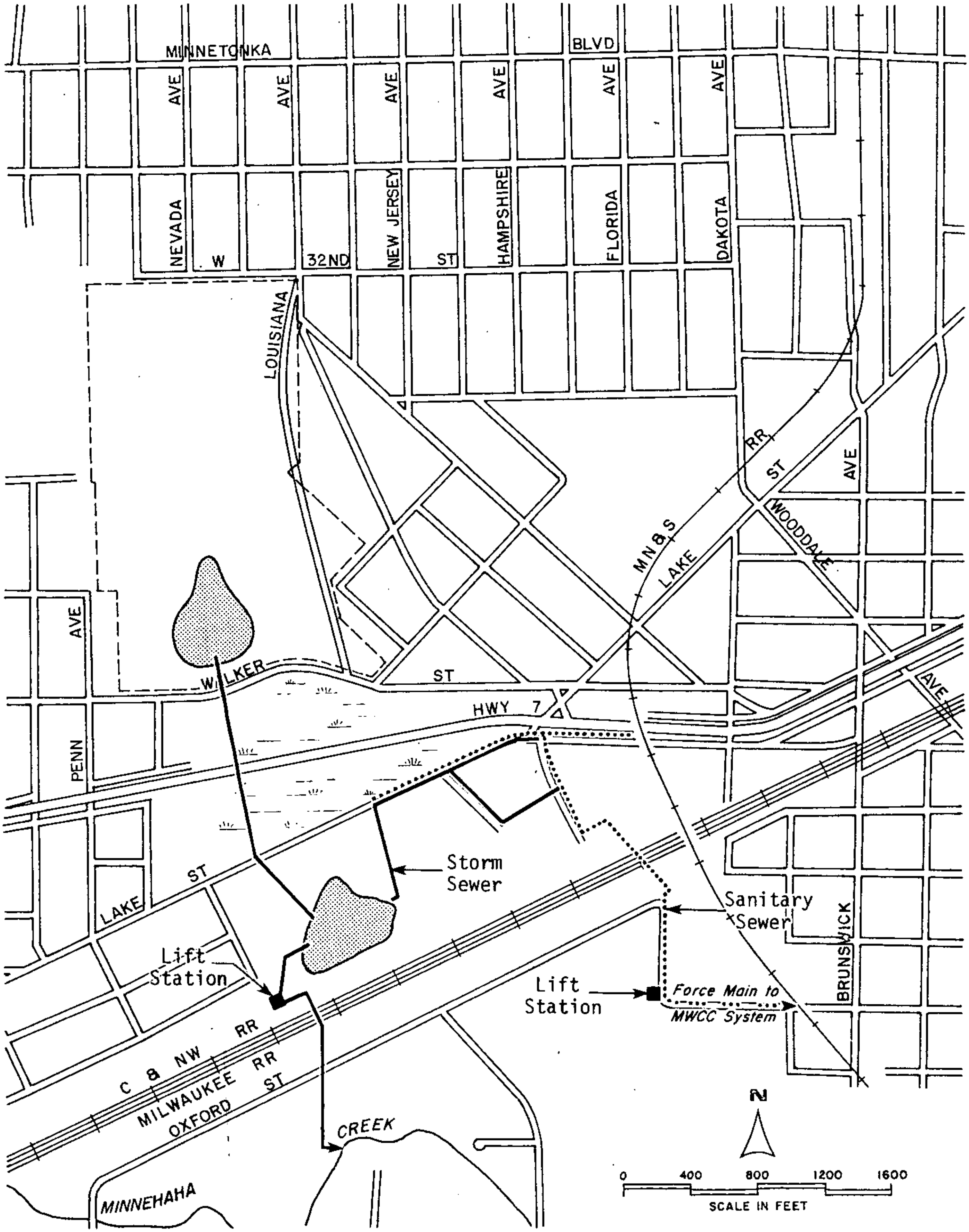


FIGURE 24

EXISTING STORM SEWER AND SANITARY SEWER SYSTEMS

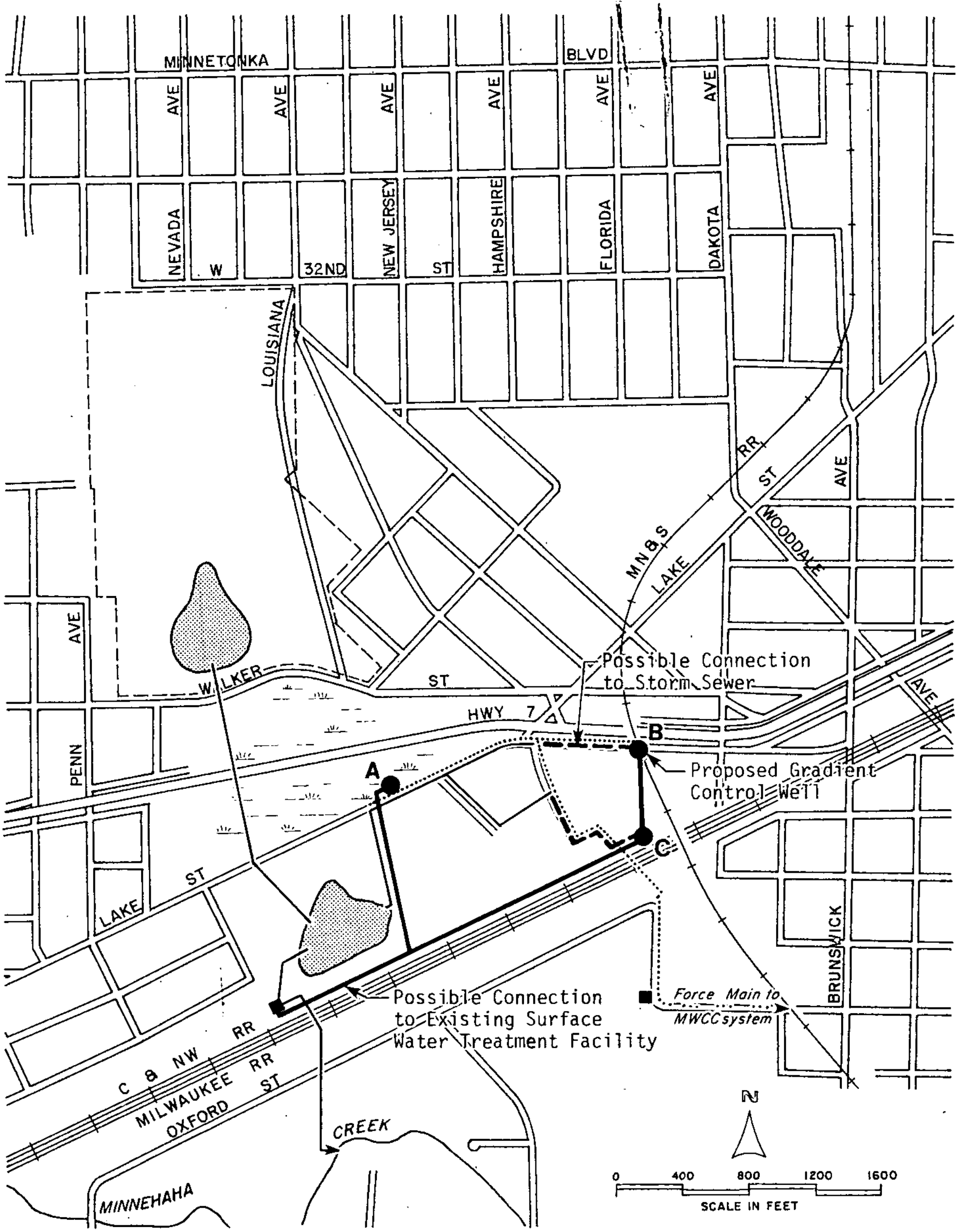


FIGURE 25
ALTERNATIVE GRADIENT CONTROL SYSTEMS

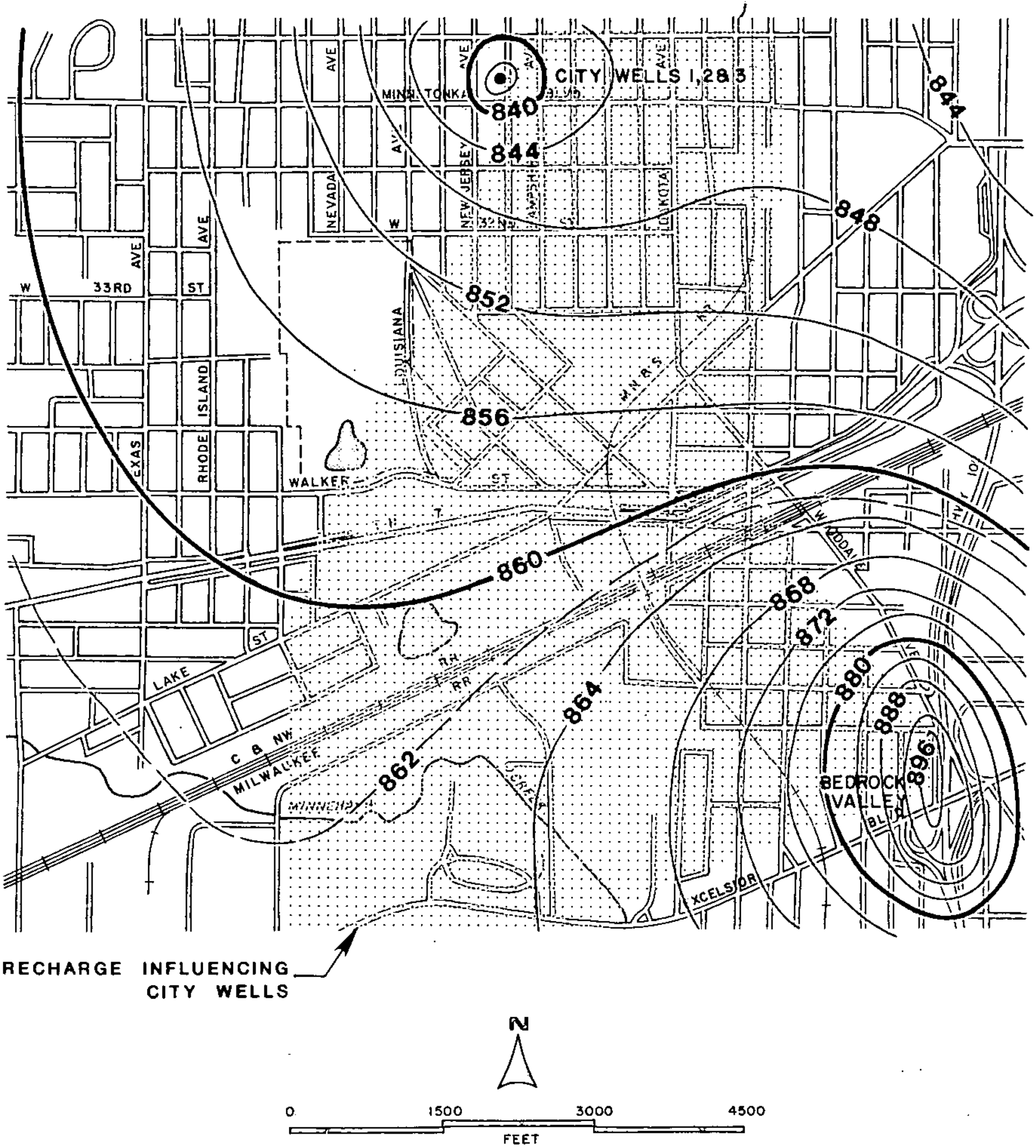


FIGURE 26

PREDICTED PIEZOMETRIC LEVELS IN THE ST. PETER AQUIFER WITH MIDCO REGISTER AND TERRY EXCAVATING WELLS ABANDONED (MSL)--SUMMER CONDITIONS

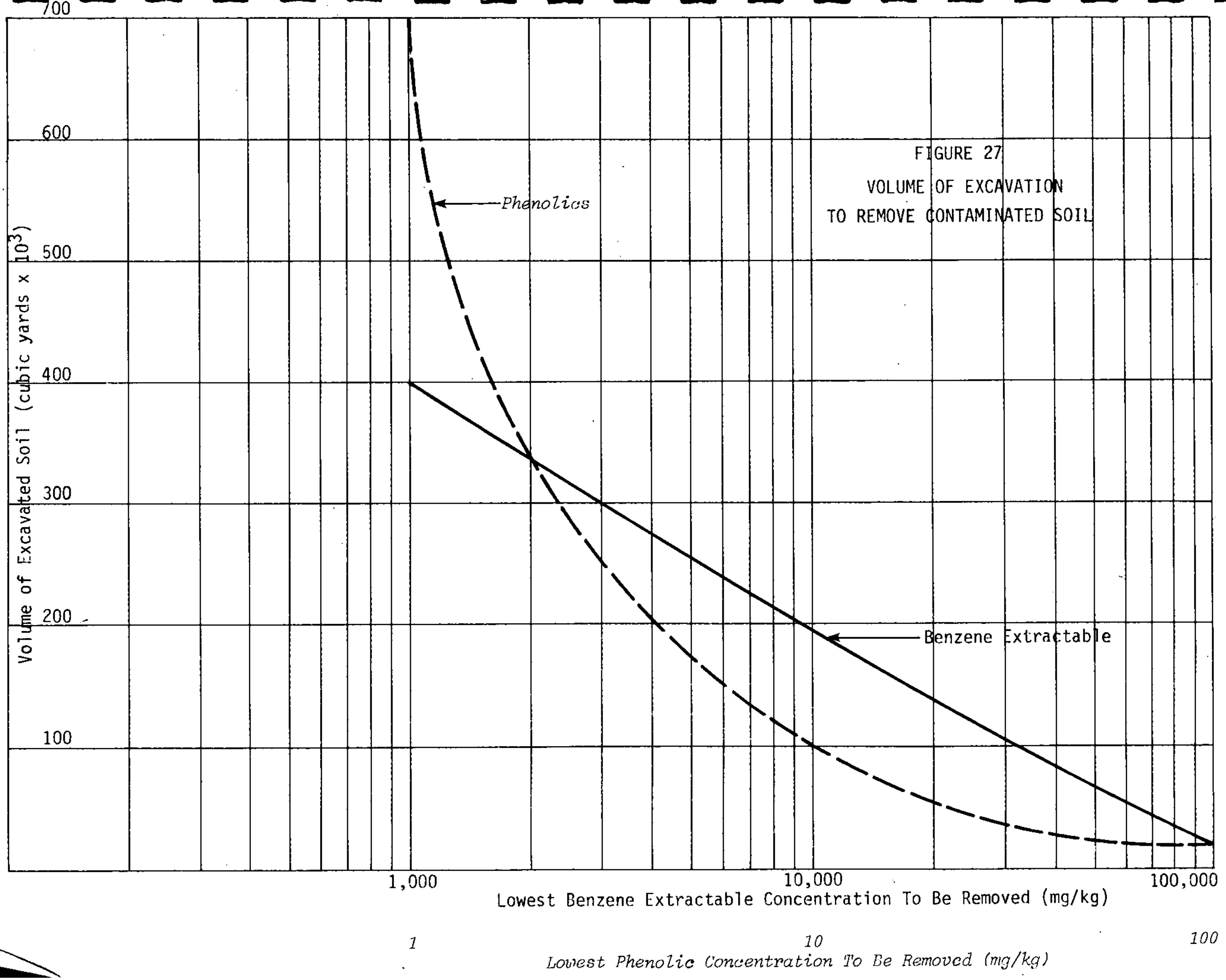


FIGURE 27
VOLUME OF EXCAVATION
TO REMOVE CONTAMINATED SOIL
Phenolics
Benzene Extractable
Volume of Excavated Soil (cubic yards x 10^3)
700
600
500
400
300
200
100
1,000
10,000
100,000
Lowest Benzene Extractable Concentration To Be Removed (mg/kg)
1
10
100
Lowest Phenolic Concentration To Be Removed (mg/kg)

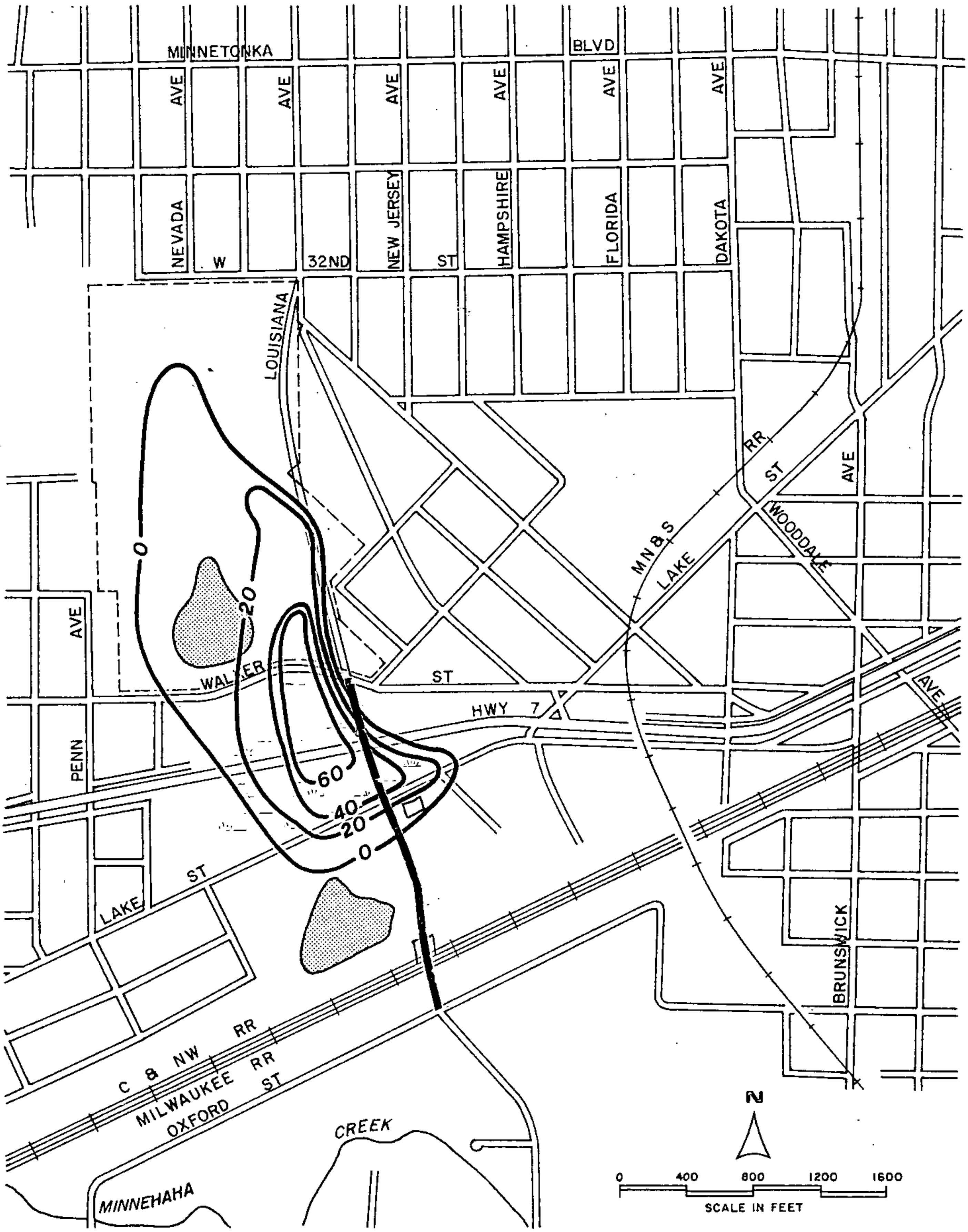


FIGURE 28

REMOVAL DEPTH CONTOURS
Soil With Phenolic Concentrations
Greater Than 1 mg/kg

Health Dept. feels this is an appropriate excavation plan if other measures fail

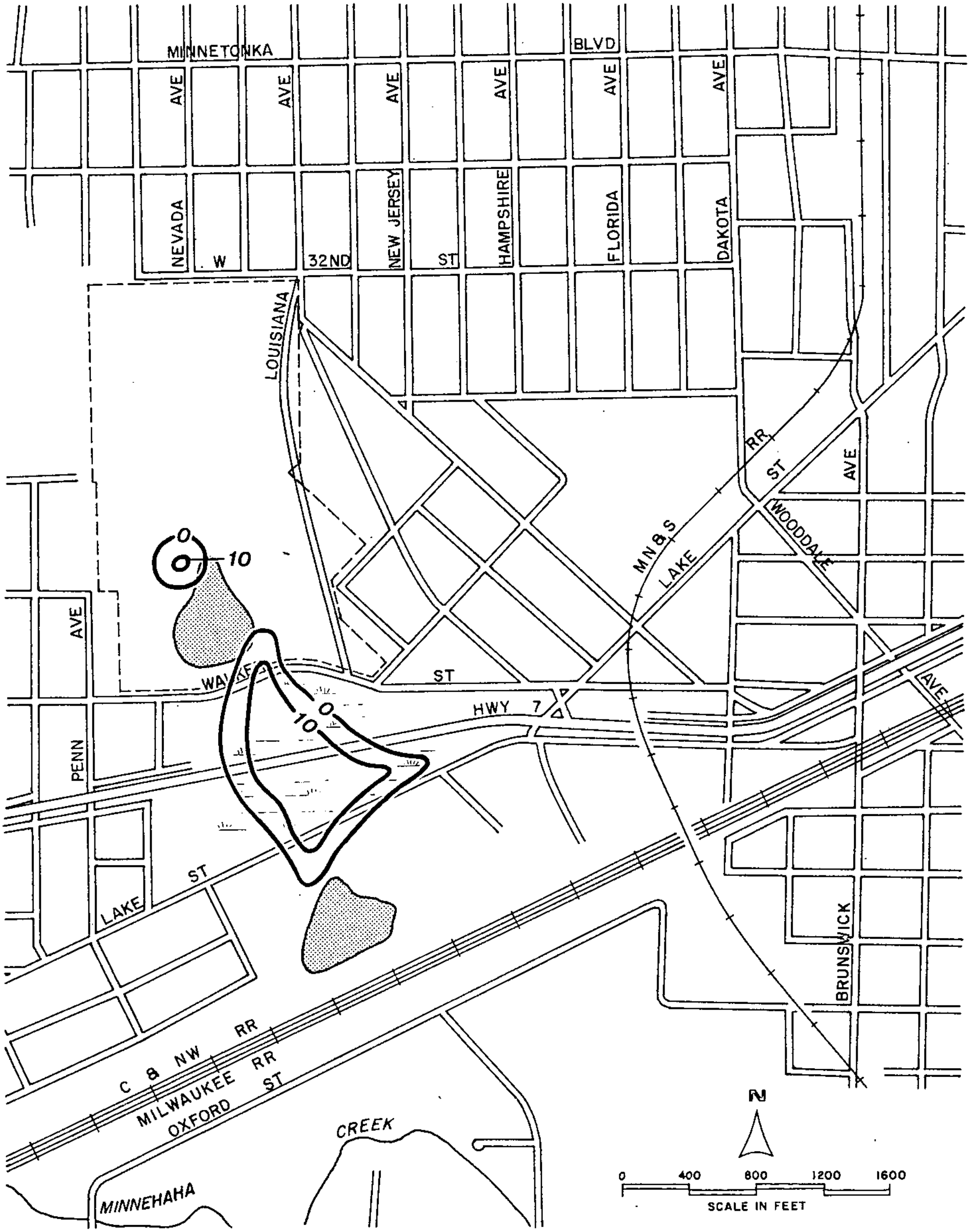


FIGURE 29

REMOVAL DEPTH CONTOURS
Soil With Phenolic Concentrations
Greater Than 10 mg/kg

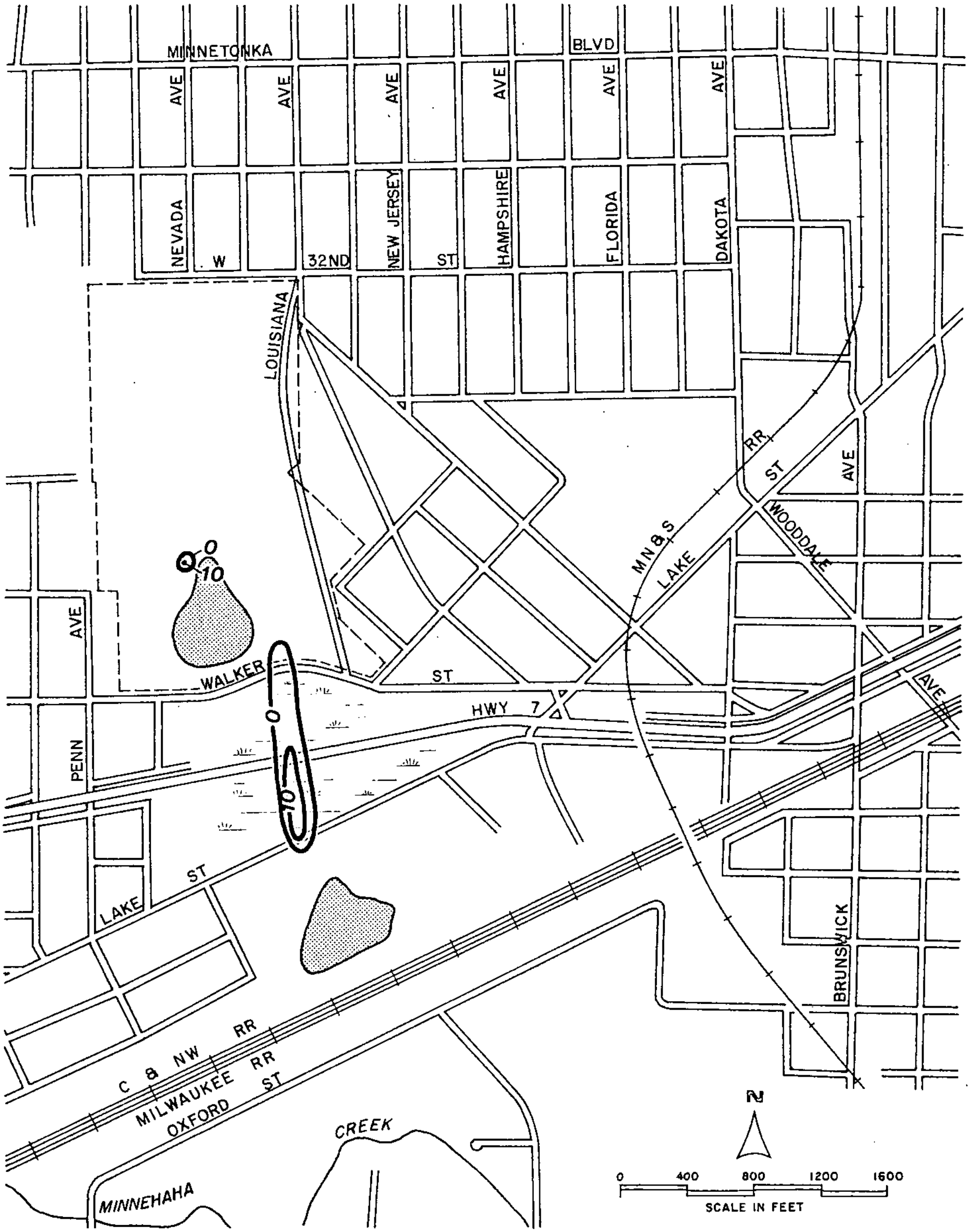


FIGURE 30

REMOVAL DEPTH CONTOURS
Soil With Phenolic Concentrations
Greater Than 100 mg/kg

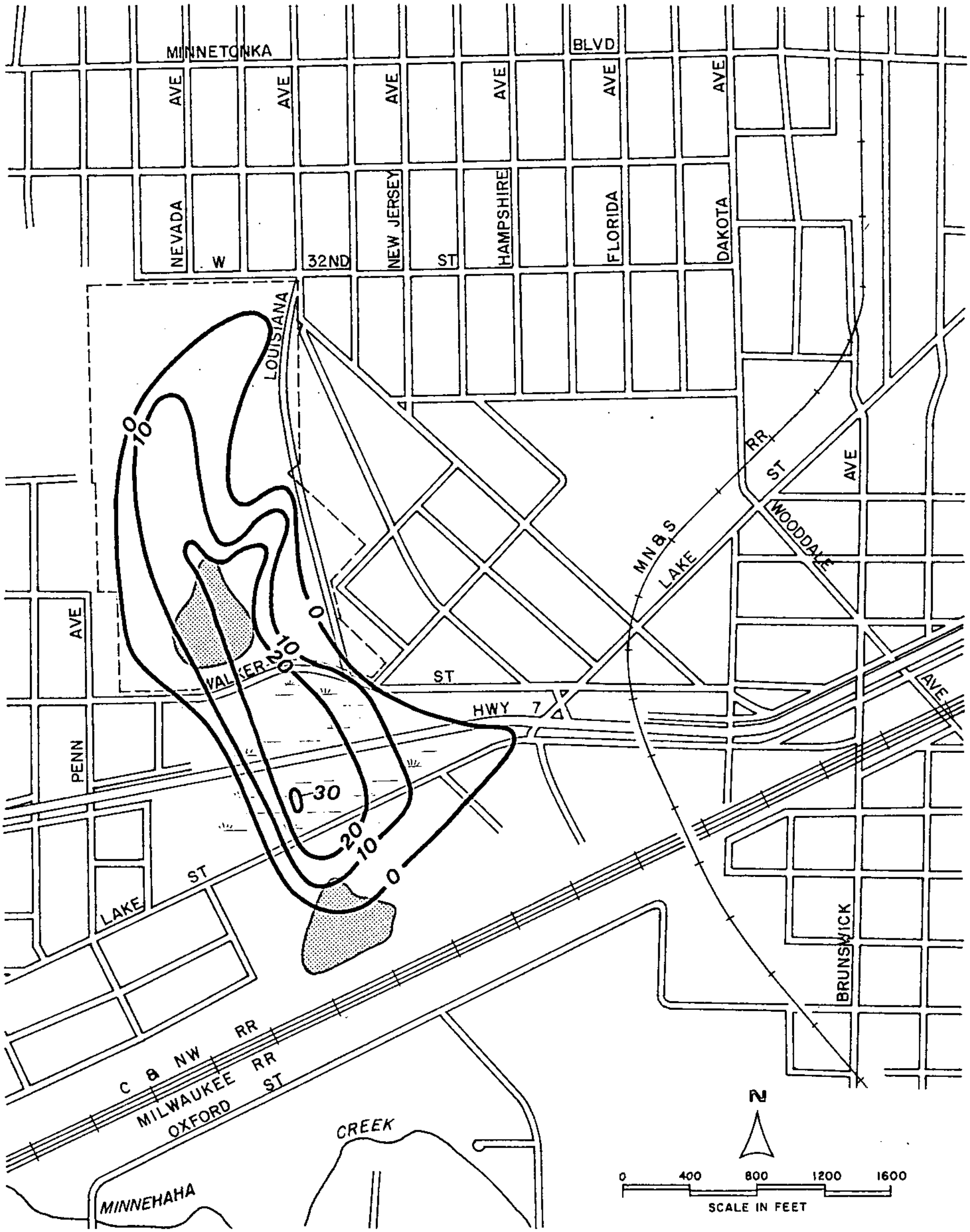


FIGURE 31

REMOVAL DEPTH CONTOURS
Soil With Benzene Extractable Concentrations
Greater Than 1,000 mg/kg

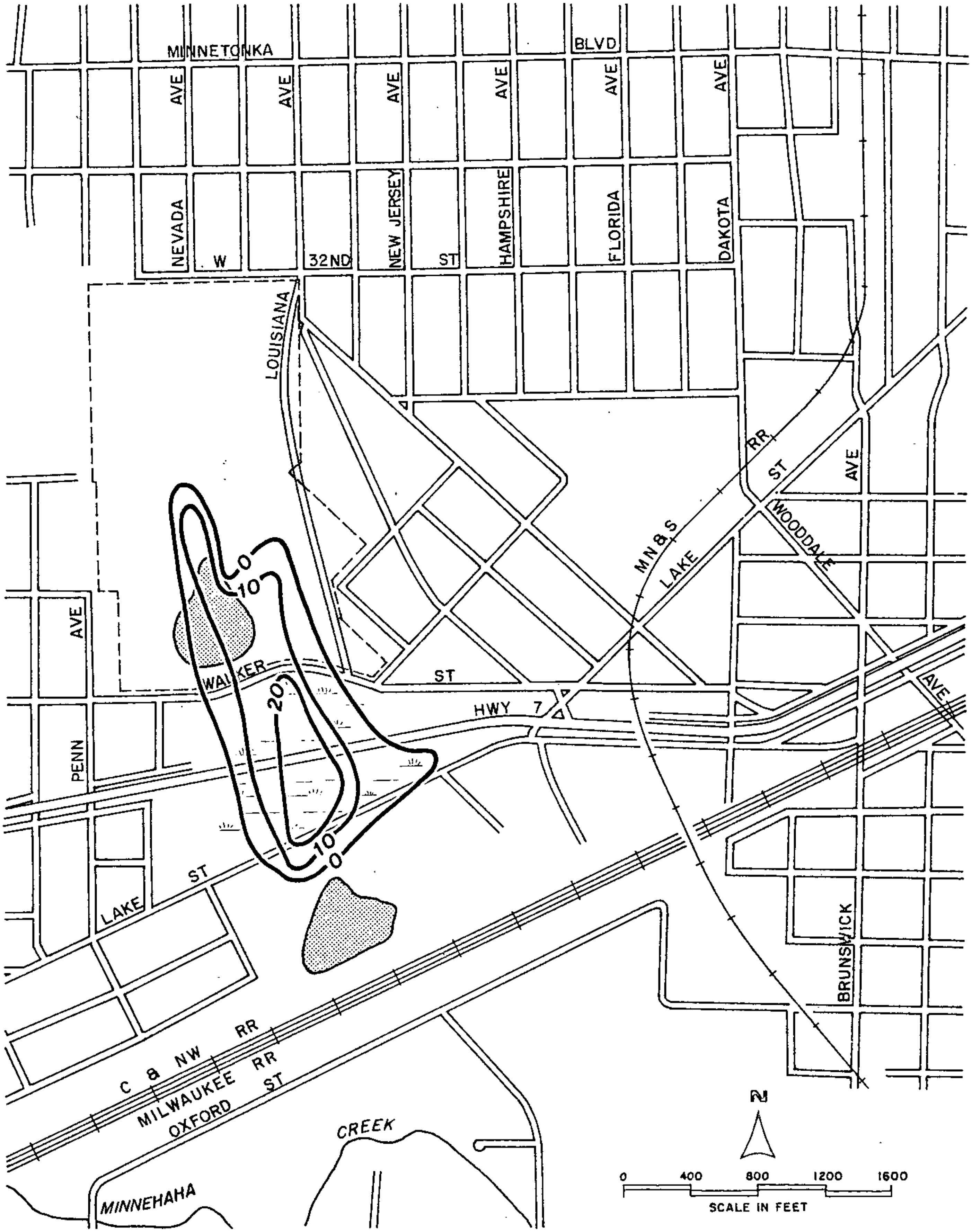


FIGURE 32

REMOVAL DEPTH CONTOURS
Soil With Benzene Extractable Concentrations
Greater Than 10,000 mg/kg

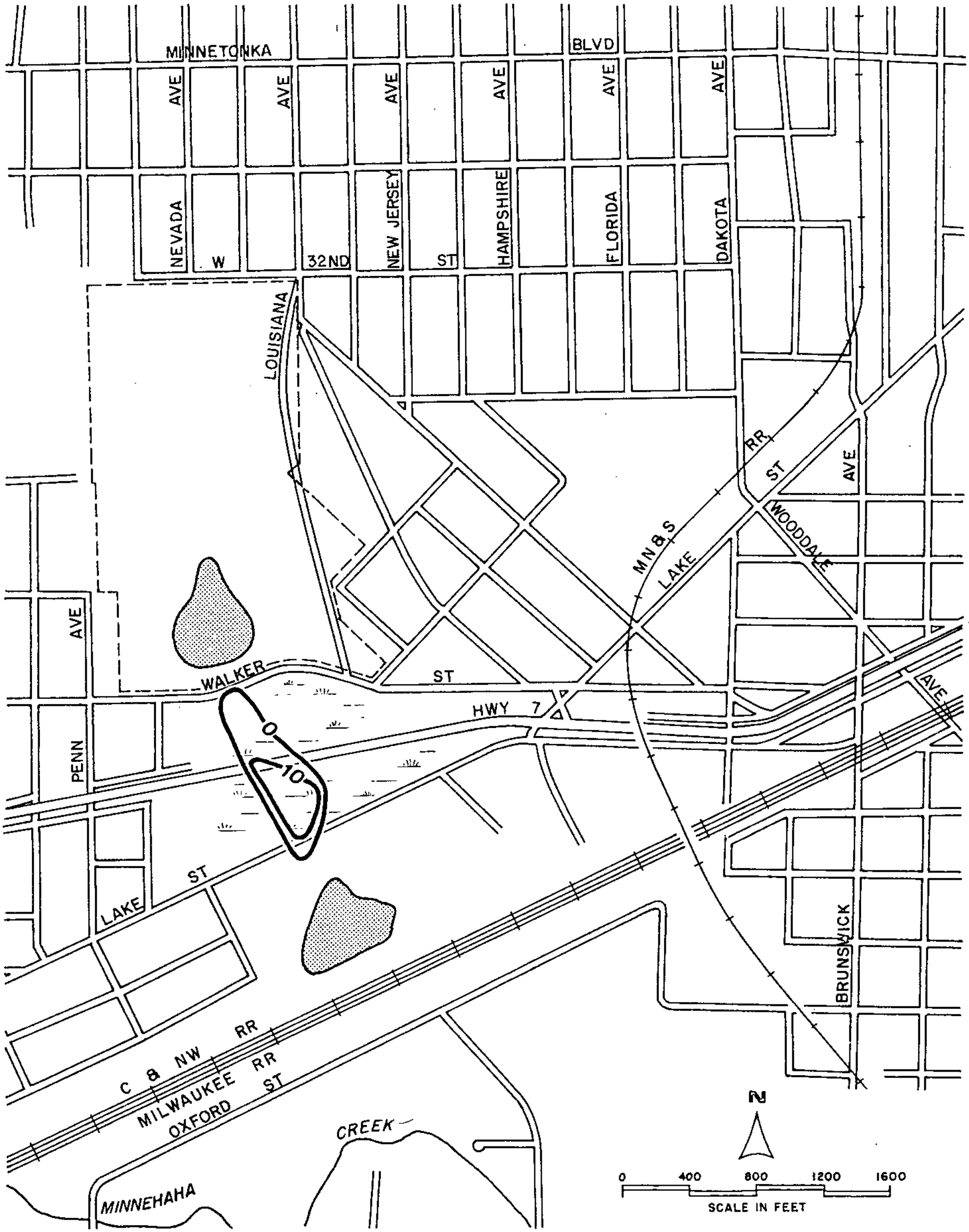


FIGURE 33

REMOVAL DEPTH CONTOURS
Soil With Benzene Extractable Concentrations
Greater Than 100,000 mg/kg

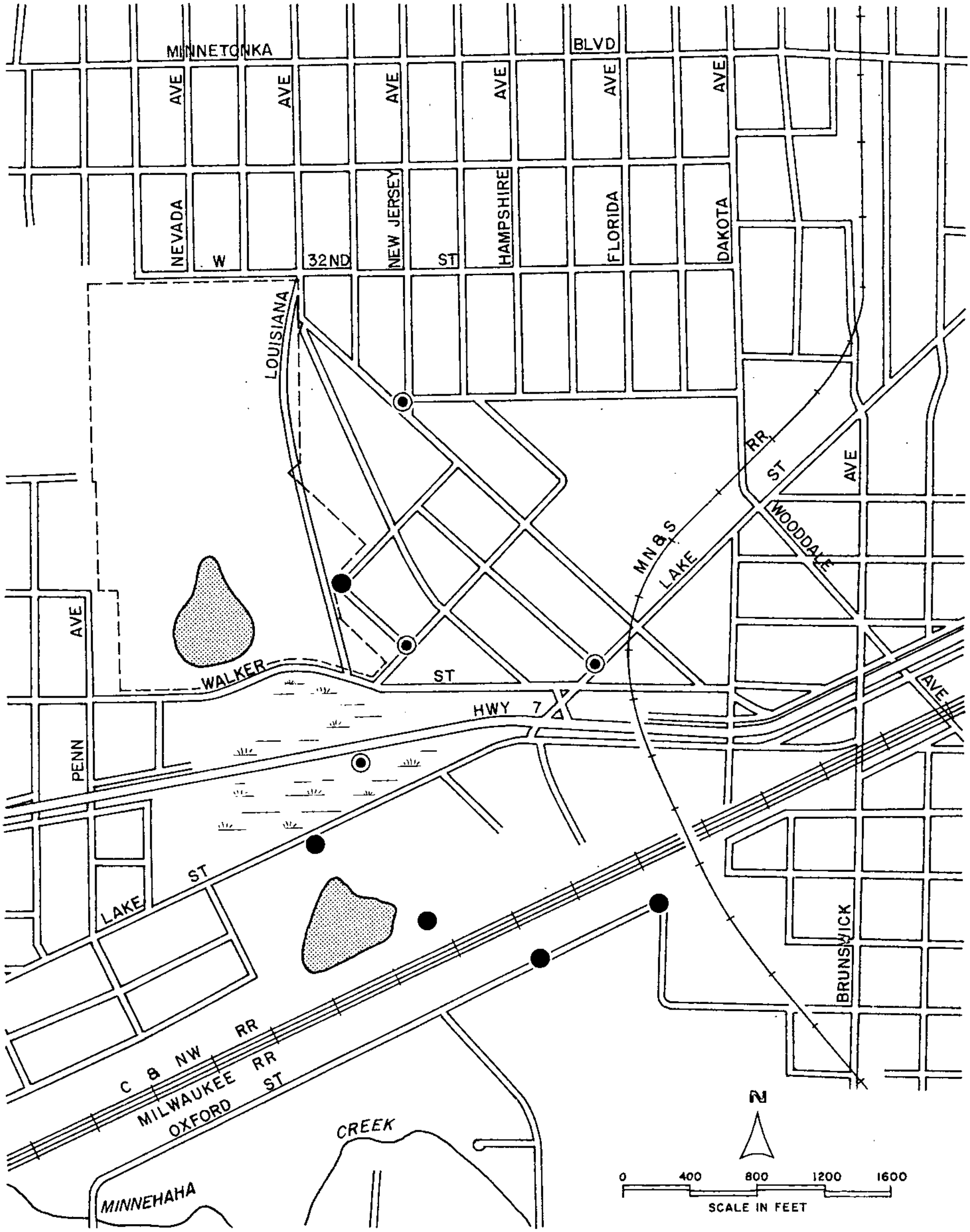


FIGURE 34

ADDITIONAL WELLS AND BORINGS NEEDED TO PLACE GRADIENT CONTROL WELLS

TABLE 1

SUMMARY OF THIN LAYER CHROMATOGRAPHY AND GAS CHROMATOGRAPHY DATA

SOIL SAMPLES

(Information in Italics Not Included in Phase I Report)

MRI Sample Number	Boring	Depth (feet)	Soil Description	Phenol (mg/Kg)	Benzene Extractable (mg/Kg)	Qualitative (POM)	Benz(c) Phenanthrene (μg/g)	Chrysene (μg/g)	Benz(a) Pyrene (μg/g)
2263	*1*	*10*	*Silty Sandy Clay*	*<.3*	*2,200*	*Abundant*	*2.2*	*--*	*.04*
2271	*1*	*55*	*Fine to Medium Sand*	*1.0*	*120*	*None*	*Not Quantitatively Analyzed*		
2345	*2*	*20*	*Fine to Medium Sand*	*1.0*	*225*	*Little*	*Not Quantitatively Analyzed*		
SS-105-1	5	5	Fill (Silty Sand)	6.6	9,300	Abundant	<0.2	10.0	<0.2
SS-105-2	5	15	Fine to Coarse Sand	1.2	1,100	*	<0.2	<3.2	<0.2
SS-105-3	5	30	Coarse Sand	<.2	155	Little	Not Quantitatively Analyzed		
SS-109-1	9	10-13	Peat	3.2	7,900	*	Not Quantitatively Analyzed		
SS-109B-1	9	30-32	Gravel	.8	735	*	0.36	49.0	0.93
SS-109A-1	9	32-33	Sand Below Thin Till Layer	.7	175	Little	Not Quantitatively Analyzed		
SS-109A-2	9	47-48	Coarse Sand	2.3	1,740	Abundant	0.25	474.5	6.9
SS-109B-2	9	48-49	Sandy Clay	7.8	170	Little	Not Quantitatively Analyzed		
SS-111-1	11	5-8	Peat	31.0	5,300	*	Not Quantitatively Analyzed		
SS-111-2	11	29-30	Medium Sand	1.1	90	*	<0.2	<3.2	<0.2
SS-111-3	11	39-42	Silty Sand	.4	85	Little	Not Quantitatively Analyzed		
3338	*Control***	*3*	*Medium Sand*	*--*	*--*	*None*	*Not Qualitatively Analyzed*		
3339	*Control***	*10-11*	*Medium Sand*	*--*	*--*	*None*	*Not Qualitatively Analyzed*		

*No qualitative estimate of the relative amount of fluorescent material was included in the MRI Report. Follow-up telephone conversations indicated that the * samples contained less fluorescent material than the samples labeled "abundant", but more than the samples labeled "little".

**Control boring placed approximately 100 feet west of T.H. 100 near Cedar Lake Road.

TABLE 2

CONSTRUCTION DATA FOR MONITORING WELLS

Well No.	Elevation Top of Pipe (MSL)	Elevation Bottom of Well (MSL)	Depth (feet)	Comments
1	922.8	815.8	107	No screen, cased to top of Platteville, 5' of open hole in Platteville.
2	897.1	861.1	36	Screened in sand and gravel in middle drift aquifer.
3	896.7	844.7	52	Screened in gravel below approximately 45' of peat and muck in middle drift aquifer.
5	891.8	865.8	25	Screened in sand and gravel in middle drift aquifer.
6	892.6	866.6	26	Screened in sand and gravel in middle drift aquifer.
7	930.0	860.0	70	Screened in fine sand in middle drift aquifer.
8	893.0	862.0	31	Screened in sand and gravel in middle drift aquifer.
9	891.3	866.3	25	Screened in sand and gravel in middle drift aquifer.
10	892.1	863.1	29	Screened in gravel in middle drift aquifer.
11	897.3	874.3	23	Screened in gravel in middle drift aquifer.
12	917.4	870.4	47	Screened in sand and gravel in middle drift aquifer.
13	891.0	841.0	50	Screened in sand and gravel in middle drift aquifer.
14	891.5	796.5	95	Screened in St. Peter sandstone.
15	892.5	816.5	76	Screened in sand and gravel in lower drift.
16	892.2	828.2	64	Screened in sand in lower drift.
17	897.4	828.4	69	Screened in silty gravel in lower drift.
P-1	929.9	821.4	108.5	Screened in silty sand in lower drift.
P-2	918.0	822.0	96	Screened in silty sand in lower drift.
P-3	892.6	822.1	70.5	Screened in silty sand in lower drift.

TABLE 3

ESTIMATED PERMEABILITIES IN GLACIAL SOILS

Boring Number	Sample Depth (feet)	Visual Soil Description	D_{80}	D_{40}	D_{10}	Permeability (cm/sec)
6	54-56	Red Silty Sandy Clay	4	.08	.003	5×10^{-6}
8	15½-17	Grey Sandy Silty Clay	.4	.01	.002	5×10^{-6}
9	25-28	Green-Grey Clay	1.3	.5	.005	1×10^{-5}
10	53-55½	Silty Sand	.4	.1	.05	2×10^{-3}
11	20-23	Coarse Sand	1	.6	.3	1×10^{-1}
11	46-48	Red Silty Sand	1.5	.3	.03	1×10^{-3}
11	54-56½	Red Silty Sandy Clay	.2	.02	.001	1×10^{-6}
12	34-36	Medium Sand	1.5	.4	.2	5×10^{-2}
12	55-57	Grey-Brown Sandy Clay	3	.2	.01	1×10^{-4}
13	30-32	Fine Sand	.3	.2	.15	1×10^{-2}
13	55-57	Fine Silty Sand	5	.3	.05	1×10^{-3}
14	54-56	Medium Sand	2	.4	.2	5×10^{-2}
14	59-62	Red Sandy Clay	>5	.4	.01	1×10^{-4}
15	35-36	Silty Sand	.4	.09	.003	1×10^{-5}
15	50-51	Grey Silty Clay	.04	.009	.002	3×10^{-6}
15	80-81	Fine Sand	.07	.06	.025	6×10^{-4}
15	95-96	Brown Silt	.06	.04	.0009	8×10^{-7}
15	105-106	Brown Silt	.15	.04	.006	4×10^{-5}
16	50-51	Brown Silt	.04	.03	.005	2×10^{-5}
16	65-66	Medium Sand	2	.6	.1	1×10^{-2}
16	90-91	Silty Sand	.6	.1	.032	1×10^{-5}
19*	12½-13½	Medium Sand	2	.6	.2	4×10^{-2}
20*	20-21	Medium Sand	1	.5	.2	5×10^{-2}

*From Soil Exploration Company Job No. 20070, 3-28-74 and 4-16-74.

TABLE 4

CHARACTERISTICS OF MUNICIPAL, INDUSTRIAL AND PRIVATE WELLS SAMPLED DURING STUDY

Well Designation	Lowest Formation	Casing Depth	Summary of Log
Flame Industries	Shakopee	257'	73' Drift; 17' Platteville; 4' Glenwood; 157' St. Peter; 84' Shakopee
Midco Register	St. Peter	?	80' Drift; 20' Platteville; 2' Glenwood; 80' St. Peter
Sterilized Diaper Service	Shakopee	292'	93' Drift; 14' Platteville; 6' Glenwood; 167' St. Peter; 62' Shakopee
Minnesota Rubber	Jordan	288'	111' Drift; 165' St. Peter; 121' Prairie du Chien; 78' Jordan
Burdick Grain	Jordan	No Log Found	--
S & K Products	Shakopee	244'	92' Drift; 2' Platteville; 171' St. Peter; 47' Shakopee
Methodist Hospital	Jordan	270'	94' Drift; 163' St. Peter; 120' Prairie du Chien; 89' Jordan; 19' St. Lawrence
Hartman Residence	St. Peter (160' deep)	?	No log available
City Well #1	St. Peter	104'	104' Drift; 32' Platteville; 154' St. Peter
City Well #3	St. Peter	103'+	103' Drift; 15' Platteville; 168' St. Peter
City Well #10	Jordan	315'	105' Drift; 20' Platteville; 165' St. Peter; 119' Prairie du Chien; 91' Jordan

TABLE 5

GROUND WATER QUALITY DATA
MONITORING WELLS PLACED FOR THIS STUDY

WELL	W-1			W-2			W-3	W-5			
LOWEST FORMATION	Platteville			Middle Drift Aquifer			Middle Drift Aquifer	Middle Drift Aquifer			
SAMPLING DATE	4/12/76	5/26/77	5/26/77 (2)	4/12/76	5/26/77	5/26/77 (2)	5/26/76	4/8/76	5/26/77	5/26/77 (2)	6/2/77
Phenolics, mg/1	<.002	<.002	<.002	<.002	<.002	<.002	<.002	.153	.022	.035	.028
Benzene Extractable, mg/1	<1	--	--	2	--	--	2	1	--	--	--
Total Organic Carbon, mg/1	--	--	--	--	--	--	--	--	--	--	--
Chemical Oxygen Demand, mg/1	--	--	--	--	--	--	--	--	--	--	64
Total Dissolved Solids, mg/1	515	--	--	683	--	--	461	557	--	--	565
Specific Conductance, umhos @ 25°C	820	00	--	1,200	--	--	750	930	--	--	--
Total Alkalinity, mg/1 as $CaCO_3$	319	--	--	366	--	--	310	410	--	--	--
Total Hardness, mg/1 as $CaCO_3$	405	--	--	518	--	--	368	418	--	--	--
Arsenic, ug/1	--	--	--	--	--	--	--	--	--	--	55
Cadmium, mg/1	--	--	--	--	--	--	--	--	--	--	<.01
Copper, mg/1	--	--	--	--	--	--	--	--	--	--	<.05
Lead, mg/1	--	--	--	--	--	--	--	--	--	--	<.1
Zinc, mg/1	--	--	--	--	--	--	--	--	--	--	.24
pH	--	--	--	--	--	--	--	--	--	--	7.1

WELL	W-6				W-7	W-8		
LOWEST FORMATION	Middle Drift Aquifer				Middle Drift Aquifer	Middle Drift Aquifer		
SAMPLING DATE	4/8/76	5/26/77	5/26/77 (2)	6/2/77	4/6/76	4/6/76	5/26/77	5/26/77 (2)
Phenolics, mg/1	.043 (2)	.088	.190	.050	<.002	<.002	<.002	<.002
Benzene Extractable, mg/1	14 (3)	--	--	--	<1	<1	--	--
Total Organic Carbon, mg/1	--	--	--	--	--	--	--	--
Chemical Oxygen Demand, mg/1	--	--	--	40	--	--	--	--
Total Dissolved Solids, mg/1	639	--	--	394	457	611	--	--
Specific Conductance, umhos @ 25°C	1,050	--	--	--	740	1,000	--	--
Total Alkalinity, mg/1 as $CaCO_3$	366	--	--	--	282	342	--	--
Total Hardness, mg/1 as $CaCO_3$	472	--	--	--	369	407	--	--
Arsenic, ug/1	--	--	--	2	--	--	--	--
Cadmium, mg/1	--	--	--	<.01	--	--	--	--
Copper, mg/1	--	--	--	<.05	--	--	--	--
Lead, mg/1	--	--	--	<.1	--	--	--	--
Zinc, mg/1	--	--	--	.05	--	--	--	--
pH	--	--	--	7.3	--	--	--	--

TABLE 5 (CONTINUED)

GROUND WATER QUALITY DATA
MONITORING WELLS PLACED FOR THIS STUDY

WELL	W-9					W-10			W-11		
LOWEST FORMATION	Middle Drift Aquifer					Middle Drift Aquifer			Middle Drift Aquifer		
SAMPLING DATE	4/1/76	2/18/77	5/26/77	5/26/77 (2)	6/2/77	4/1/76	5/26/76	5/26/76 (2)	12/9/76	5/26/76	5/26/76 (2)
Phenolics, mg/l	3.00	.76	.60	1.100	.60	<.002	.004	17	.022	.004	.023
Benzene Extractable, mg/l	4	37	--	--	--	<1	--	--	--	--	--
Total Organic Carbon, mg/l	--	--	--	--	--	--	--	--	25	--	--
Chemical Oxygen Demand, mg/l	--	--	--	--	92	--	--	--	--	--	--
Total Dissolved Solids, mg/l	844	--	--	--	876	650	--	--	--	--	--
Specific Conductance, umhos @ 25°C	1,375	--	--	--	--	1,000	--	--	--	--	--
Total Alkalinity, mg/l as $CaCO_3$	528	--	--	--	--	472	--	--	--	--	--
Total Hardness, mg/l as $CaCO_3$	272	--	--	--	--	516	--	--	--	--	--
Arsenic, ug/l	--	--	--	--	6	--	--	--	--	--	--
Cadmium, mg/l	--	--	--	--	<.01	--	--	--	--	--	--
Copper, mg/l	--	--	--	--	<.05	--	--	--	--	--	--
Lead, mg/l	--	--	--	--	<.1	--	--	--	--	--	--
Zinc, mg/l	--	--	--	--	.03	--	--	--	--	--	--
pH	--	--	--	--	7.2	--	--	--	--	--	--

WELL	W-12	W-13						W-14			W-15	
LOWEST FORMATION	Middle Drift Aquifer	Middle Drift Aquifer						St. Peter			Lower Drift	
SAMPLING DATE	12/10/76	12/2/76	2/18/77	5/26/77	5/26/77 (2)	6/2/77	6/22/77	2/18/77	5/26/77	5/26/77 (2)	5/26/77	5/26/77 (2)
Phenolics, mg/l	.014	--	4.8	51	56	49	50	<.002	<.002	.0068	.028	.037
Benzene Extractable, mg/l	--	--	--	--	--	--	--	--	--	--	--	--
Total Organic Carbon, mg/l	12	--	1,171	--	--	--	--	5.0	--	--	--	--
Chemical Oxygen Demand, mg/l	--	--	--	--	--	25,800	40,200	--	--	--	--	--
Oil and Grease, mg/l	--	--	--	--	--	--	4,900	--	--	--	--	--
Total Dissolved Solids, mg/l	--	--	--	--	--	1,617	--	--	--	--	--	--
Specific Conductance, umhos @ 25°C	--	--	--	--	--	--	--	--	--	--	--	--
Total Alkalinity, mg/l as $CaCO_3$	--	--	--	--	--	--	--	--	--	--	--	--
Total Hardness, mg/l as $CaCO_3$	--	--	--	--	--	--	--	--	--	--	--	--
Arsenic, ug/l	--	--	--	--	35	--	--	--	--	--	--	--
Cadmium, mg/l	--	--	--	--	--	<.01	--	--	--	--	--	--
Copper, mg/l	--	--	--	--	--	<.05	--	--	--	--	--	--
Lead, mg/l	--	--	--	--	--	<.1	--	--	--	--	--	--
Zinc, mg/l	--	--	--	--	--	.09	--	--	--	--	--	--
pH	--	--	--	--	--	7.6	7.5	--	--	--	--	--
Suspended Solids, mg/l	--	--	--	--	--	--	486	--	--	--	--	--

TABLE 5 (CONTINUED)

GROUND WATER QUALITY DATA
MONITORING WELLS PLACED FOR THIS STUDY

WELL	W-16			W-17				
LOWEST FORMATION	Lower Drift			Lower Drift				
SAMPLING DATE	4/19/77	5/26/77	5/26/77(2)	4/19/77	5/26/77	5/26/77(2)	6/2/77	6/22/77
Phenolics, mg/l	.002	.004	<.002	.28	.14	.340	.18	0.032
Benzene Extractable, mg/l	--	--	--	--	--	--	--	--
Total Organic Carbon, mg/l	141	--	--	105	--	--	--	--
Chemical Oxygen Demand, mg/l	--	--	--	--	--	--	40	787
Oil and Grease, µg/l	--	--	--	--	--	--	--	<1
Total Dissolved Solids, mg/l	--	--	--	--	--	--	705	--
Specific Conductance, umhos @ 25°C	--	--	--	--	--	--	--	--
Total Alkalinity, mg/l as $CaCO_3$	--	--	--	--	--	--	--	--
Total Hardness, mg/l as $CaCO_3$	--	--	--	--	--	--	--	--
Arsenic, ug/l	--	--	--	--	--	--	3	--
Cadmium, mg/l	--	--	--	--	--	--	<.01	--
Copper, mg/l	--	--	--	--	--	--	<.05	--
Lead, mg/l	--	--	--	--	--	--	<.1	--
Zinc, mg/l	--	--	--	--	--	--	.06	--
pH	--	--	--	--	--	--	7.4	--

(2) Data from Minnesota Department of Health (1977).

TABLE 6

GROUND WATER QUALITY DATA
MUNICIPAL WELLS

Well	CW-1		CW-3				
Lowest Formation	St. Peter		St. Peter				
Sampling Date	9/73-2/74[1]	4/1/76	9/73-2/74[1]	4/1/76	5/26/77	5/26/77[2]	6/9/77[3]
Phenolics, mg/1	<.002-.035	<.002	<.002-.006	<.002	.002	<.002	<.002

Well	CW-10				
Lowest Formation	Prairie du Chien-Jordan				
Sampling Date	9/73-2/74[1]	4/1/76	5/26/77	5/26/77[2]	6/9/77[3]
Phenolics, mg/1	<.002-.013	<.002	.005	.0059	<.002

(1) Data from Minnesota Department of Health (1974).
(2) Data from Minnesota Department of Health (1977).
(3) Three samples collected--all values <.002 mg/1.

TABLE 7

GROUND WATER QUALITY DATA
INDUSTRIAL AND RESIDENTIAL WELLS

Well	FLAME INDUSTRIES					MID CO REGISTER (ROBINSON RUBBER)			
Lowest Formation	Prairie-du-Chien-Jordan (Cased Through St. Peter)					St. Peter (Cased Through Drift)			
Sampling Date	12/73 to 2/74(1)	4/1/76	5/26/77	5/26/77(2)	6/9/77	12/73 to 2/74(1)	4/1/76	5/26/77	5/26/77(2)
Phenolics, mg/l	.002-.004	<.002	.004	.033	<.002	1.0-1.4	.170	.140	.390
Benzene Extractable, mg/l	--	1	--	--		--	2	--	--

Well	STERILIZED DIAPER SERVICE	MINNESOTA RUBBER		BURDICK GRAIN	
Lowest Formation	Prairie-du-Chien-Jordan	Prairie-du-Chien-Jordan		Prairie-du-Chien-Jordan	
Sampling Date	9/15/76	12/73 to 2/74(1)	9/15/76	1/74 to 2/74(1)	9/15/76
Phenolics, mg/l	<.002	<.002-.009	<.002	<.002-.017	<.002

Well	S & K PRODUCTS		METHODIST HOSPITAL	HARTMAN RESIDENCE
Lowest Formation	Prairie-du-Chien-Jordan		Prairie-du-Chien-Jordan	St. Peter (Cased Through Drift)
Sampling Date	12/73 to 2/74(1)	9/13/76	9/15/76	9/24/76
Phenolics, mg/l	<.002-.007	<.002	<.002	.002

(1) Data from Minnesota Department of Health (1974).
(2) Data from Minnesota Department of Health (1977).

TABLE 8

ESTIMATED ANTICIPATED PEAK AND AVERAGE RATIOS BETWEEN VARIOUS PARAMETERS IN DISCHARGE FROM GRADIENT CONTROL WELLS*

	WELL A		WELLS B & C		ALL WELLS	
Water Quality Parameter	Estimated Peak Concentration	Ratio Between Phenolics and Other Parameters	Estimated Peak Concentration	Ratio Between Phenolics and Other Parameters	Estimated Peak Concentration	Ratio Between Phenolics and Other Parameters
Phenolic Substances, mg/1	3-8	1	0.2-0.3	1	1-3	1
Chemical Oxygen Demand, mg/1	2000-5400	700	40-600	200-2000	600-1800	600
Oil and Grease, mg/1	300-800	100	6-30	30-100	1700	600-1700
Polynuclear Aromatic Hydrocarbons, mg/1	150-400	50	10	50	100	50
5-Day Biochemical Oxygen Demand, mg/1	200-500	70	30-500	150-1500	100-300	100

*These are the best estimates possible based on available ground water quality data. Data should be considered order of magnitude estimates at best. Each well is assumed to pump 15 gpm.

TABLE 9

MWCC LIMITATIONS FOR
DISCHARGES TO THE SANITARY SEWER*

Substance or Characteristic	Limit
Cadmium, mg/l	2.0
Chromium (total), mg/l	25.0
Chromium (hexavalent), mg/l	10.0
Copper, mg/l	5.0
Cyanide (total), mg/l	10.0
Cyanide (readily released at 150°F and pH = 5.5), mg/l	2.0
Iron, mg/l	50.0
Lead, mg/l	0.5
Mercury, mg/l	None at levels acutely toxic to humans or other animals or plant life.
Nickel, mg/l	10.0
Zinc, mg/l	15.0
Temperature (except where higher temperatures are required by law), °F	≤150
pH, units	5.5-9.5
Oil and Grease (hexane soluble), mg/l	100

*Source: "Sewage and Waste Control Rules and Regulations for the Metropolitan Disposal System," Metropolitan Sewer Board, December 1, 1971.

TABLE 10

STANDARDS FOR DISCHARGES OF STORM WATER FROM SITE TO MINNEHAHA CREEK[a]

Substance or Characteristic	Permissible Concentration With Dilution	Permissible Daily Maximum Concentration
Oil and Grease, mg/l	0.5x[b]	15
Phenols, mg/l	0.01x	0.1
5-Day Biochemical Oxygen Demand, mg/l	5x	45
Total Suspended Solids, mg/l	5x	45
Total Chlorine Residual, mg/l	0.01x	0.2
Zinc, mg/l	0.12x	1.0
Cadmium, mg/l	0.03x	0.2
Copper, mg/l	0.01x	0.5
Nickel, mg/l	0.52x	2.0
Lead, mg/l	0.03x	1.0
Ammonia, mg/l as N	1.0x	2.0
Benzo-α-pyrene, mg/l	--	0.00001
Chrysene, mg/l	--	0.00001
pH, units	--	6.5-8.5

[a]Source: NPDES Permit No. MN 0045489. Refer to permit for additional detail.

[b] $x = \frac{(0.25)(\text{flow in Minnehaha Creek})+(\text{effluent flow rate})}{(\text{effluent flow rate})}$

Flows used in calculation of dilution ratio "x" shall be the daily total effluent flow rate and the daily total flow rate for Minnehaha Creek.

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A P P E N D I X   A

MIDWEST RESEARCH INSTITUTE'S REPORT
ON SOIL SAMPLE ANALYSES

MIDWEST RESEARCH INSTITUTE
425 Volker Boulevard
Kansas City, Missouri 64110
Telephone (816) 561-0202

July 9, 1976

Mr. William A. O'Connor
Director of Laboratory Services
SERCO Laboratory, Inc.
2982 North Cleveland Avenue
Roseville, Minnesota 55113

Subject: Letter Report, MRI Project No. 5-1492-C(2), "Analysis of Polynuclear Organic Materials (POMs) in Five Soil Samples."

Dear Bill:

This report describes the results of our thin-layer chromatographic (TLC) screening of five soil samples for POMs and our gas chromatographic (GC) examination of one of those soil extracts.

The five soil samples, SERCO Samples Nos. 2263, 2271, 2345, 3338, and 3339, were extracted and screened by TLC, and Sample No. 2263 was examined by GC according to procedures described in MRI's Final Report for Project No. 5-1492-C, "Analysis of Polynuclear Organic Materials (POMs) in Soil and Water - Phase I," dated May 5, 1976. Table 1 shows the moisture contents of the soils and Table 2 summarizes the results of the TLC screening. The TLC plates are reproduced in Figure 1. Since only Sample No. 2263 exhibited more than a trace of POMs, this sample was examined by GC. Although the chromatogram, shown in Figure 2, contained a number of large peaks, only three matched the retention times of compounds in the mixed POM standard utilized. Sample No. 2263 was found to contain 2.2 µg/g of benz[c]phenanthrene, 0.05 µg/g of 7,12-dimethylbenz[a]anthracene, and 0.04 µg/g of benz[a]pyrene on a dry weight basis. Since the identity assignments were based solely on GC retention times, additional GC and GC/MS examination would be required to positively identify these materials and compounds represented by other peaks in the chromatogram.

Sincerely yours,

MIDWEST RESEARCH INSTITUTE

Clarence L. Haile

Clarence L. Haile
Associate Analytical Chemist

Approved:

F. I. Metz, Assistant Director
Physical Sciences Division

TABLE 1

MOISTURE CONTENT OF SOIL SAMPLES FOR POM ANALYSIS

Sample Number	Percent Water
2263	30.0
2271	13.1
2345	12.9
3338	3.7
3339	3.6

TABLE 2

SUMMARY OF TLC SCREENING

Sample	R_f Decade							
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
Anthracene						0.58		
Chrysene						0.58		
Benz[a]pyrene						0.57		
2263	0.08	0.14	0.24	0.35		0.54	0.62	
	0.04							
2271						0.57 (faint)		
2345						0.55 (faint)		
3338	(no bands detected)							
3339	(no bands detected)							

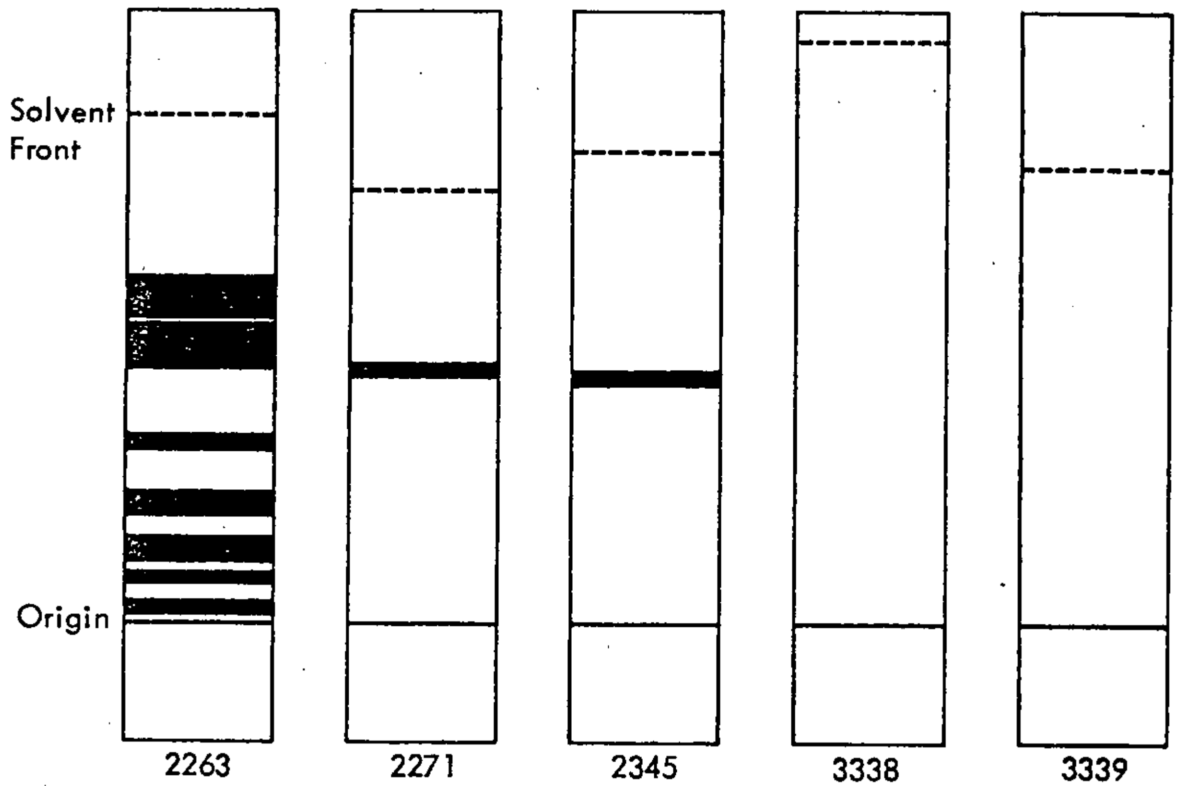


Figure 1 - Reproductions of TLC Plates Under Long Ultraviolet Light

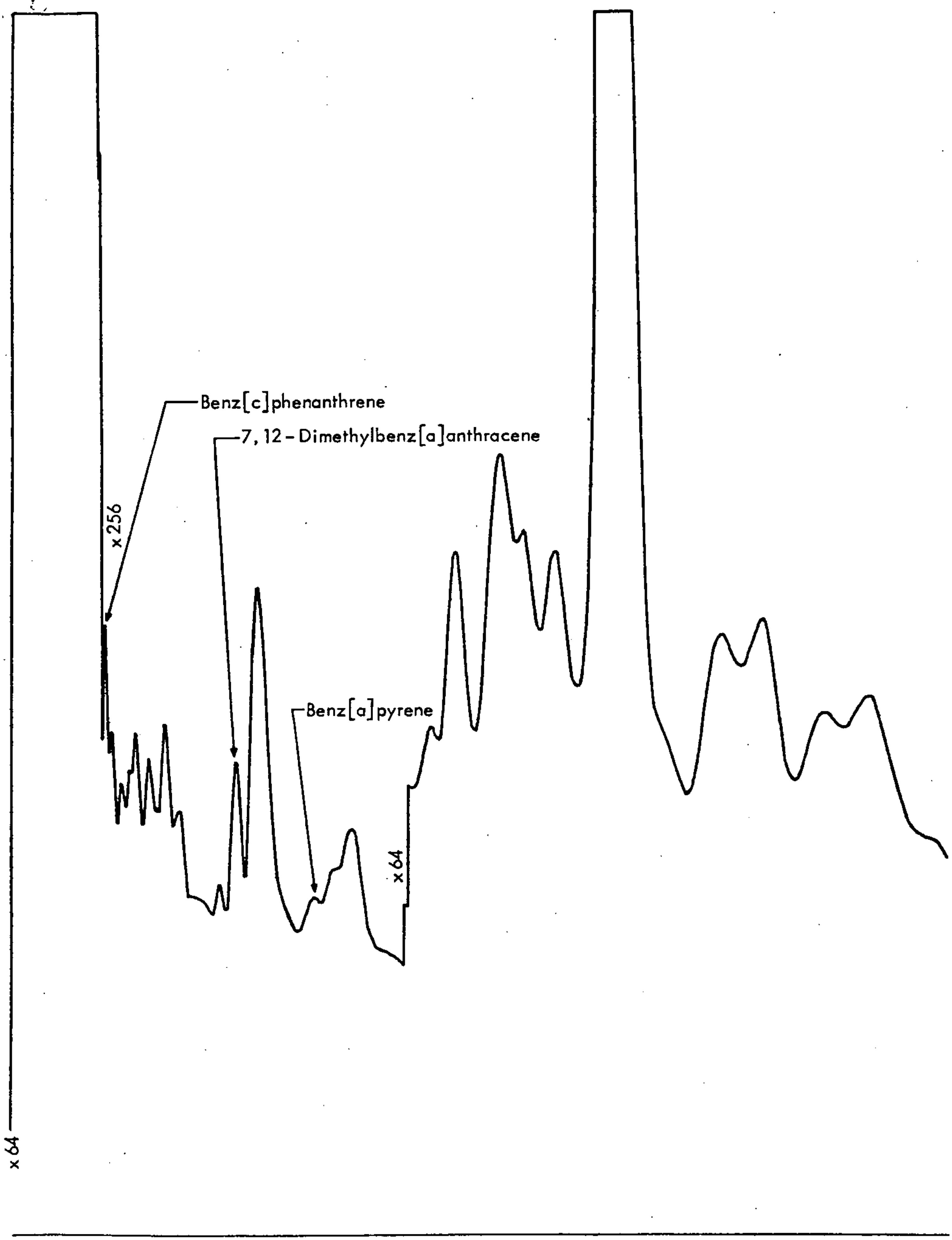


Figure 2 - GC of Sample No. 2263

SERCO
ELY • ROSEVILLE
SANITARY ENGINEERING LABORATORIES, INC.
2982 N. Cleveland Ave. Roseville, Mn. 55113 (612) 636-7173

GERALD ALLEN, P.E.
LAWRENCE BREIMHURST, P.E.

July 12, 1976

Mr. Allan Gebhard
Barr Engineering Company
6800 France Avenue South
Minneapolis, Minnesota 55435

Dear Mr. Gebhard:

Enclosed is a report from the Midwest Research Institute for the analysis of Polynuclear Organic Materials (POM's) in five soil samples. The samples are identified in the Midwest Research Report by SERCO's laboratory numbers. The table provided below identifies each sample according to sample site.

SERCO Lab. No.	Sample Site Boring No.	Sample Site Depth, ft.	Date Collected
2263	1	10	11-14-75
2271	1	55	11-25-75
2345	2	20	11-26-75
3338	C-1	2½ - 3½	5-17-76
3339	C-1	10-11	5-18-76

If you have any questions or comments concerning this matter, please feel free to contact us at any time.

Yours truly,

SERCO LABORATORIES

William A. O'Connor

William A. O'Connor, Chemist
Director of Laboratory Services

WAO/mm
Enclosure

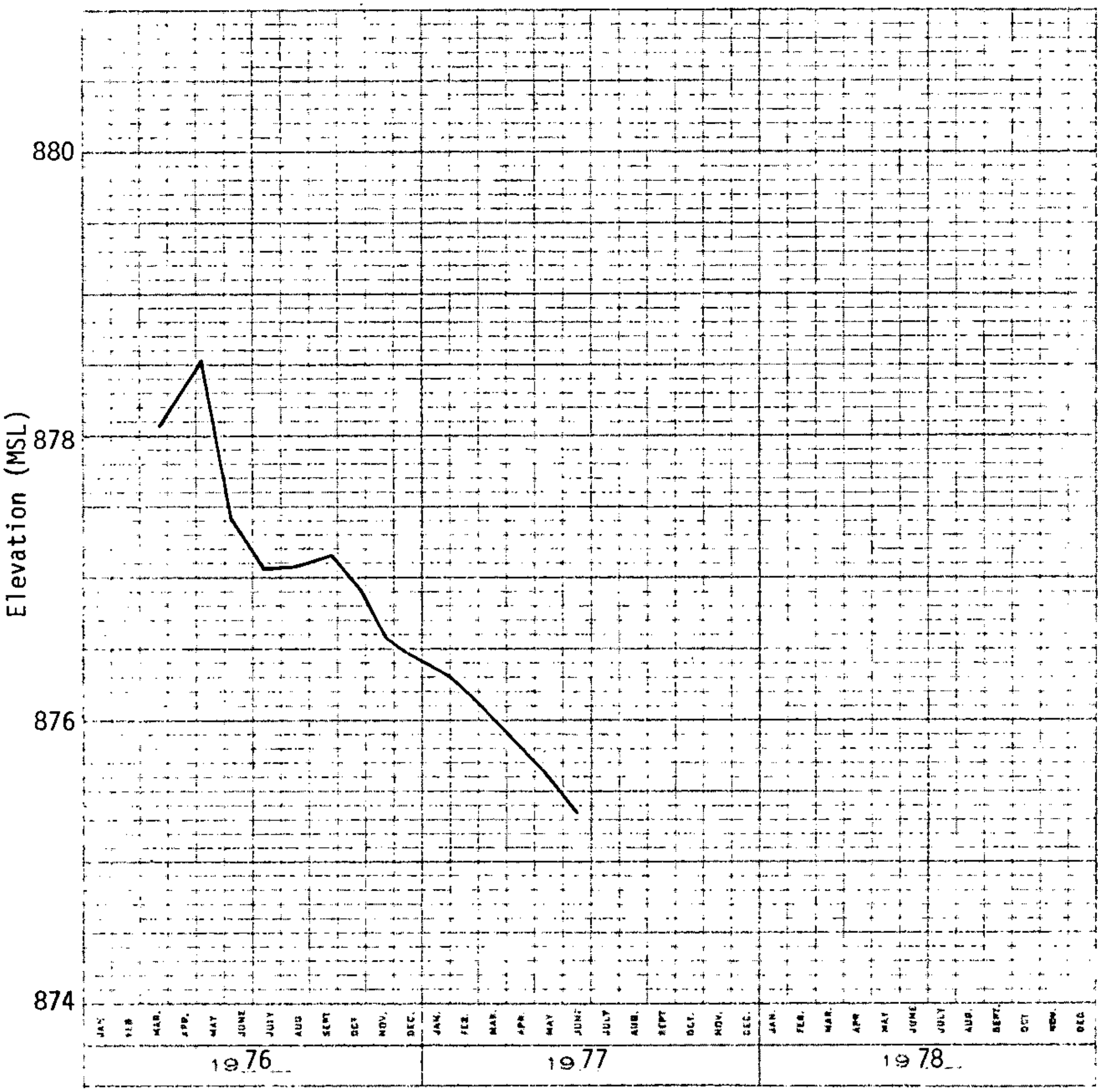
A P P E N D I X B

GROUND WATER HYDROGRAPHS FOR STUDY MONITORING WELLS

GROUND WATER HYDROGRAPH

MONITORING WELL 1

LOCATION: Hampshire Avenue Between West 31st Street & Minnetonka Boulevard (Platteville Formation)



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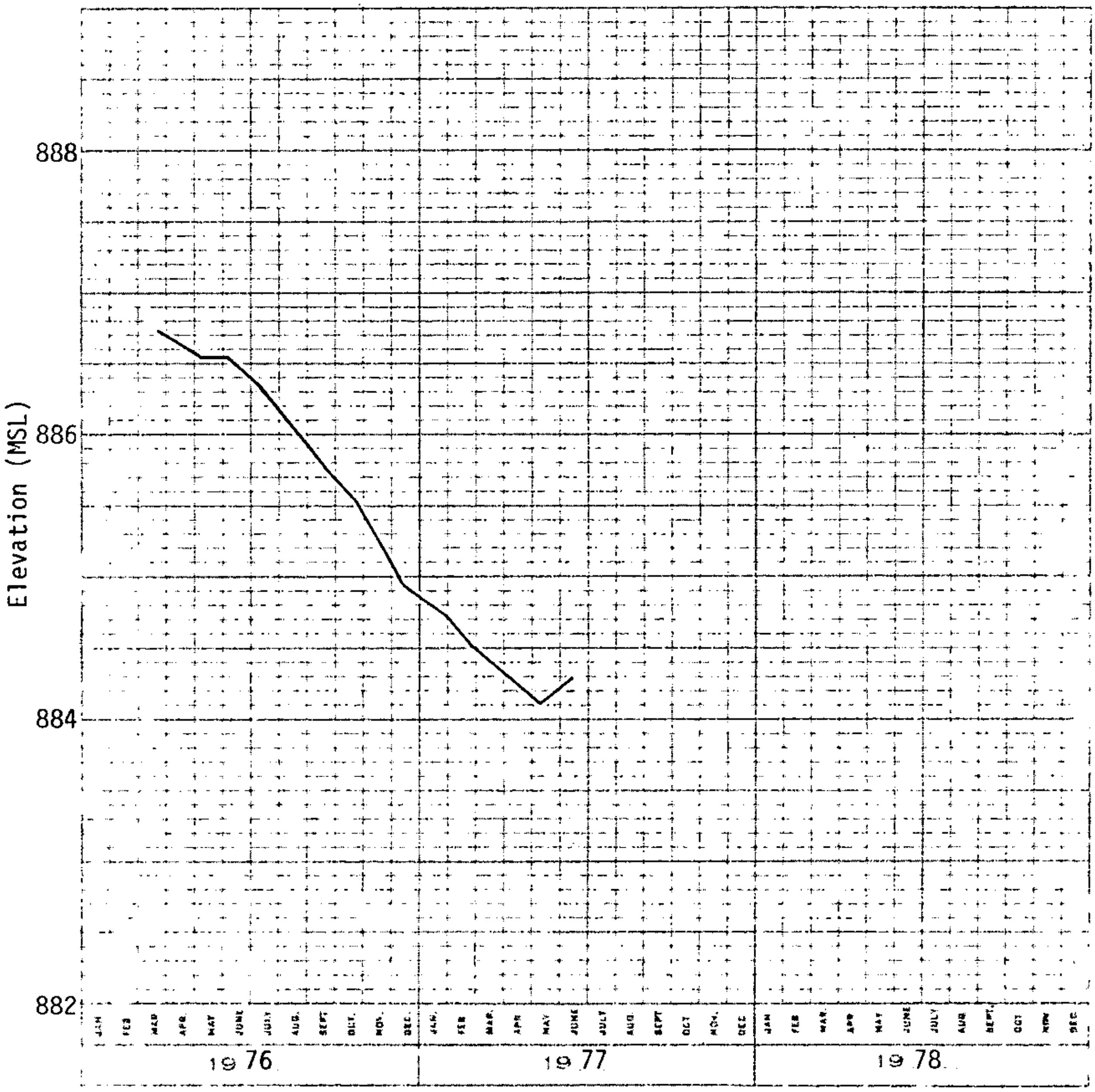
CONSULTING ENGINEERS

GROUND WATER HYDROGRAPH

MONITORING WELL 2

LOCATION: Oregon Avenue & West 31st Street
(middle drift aquifer)

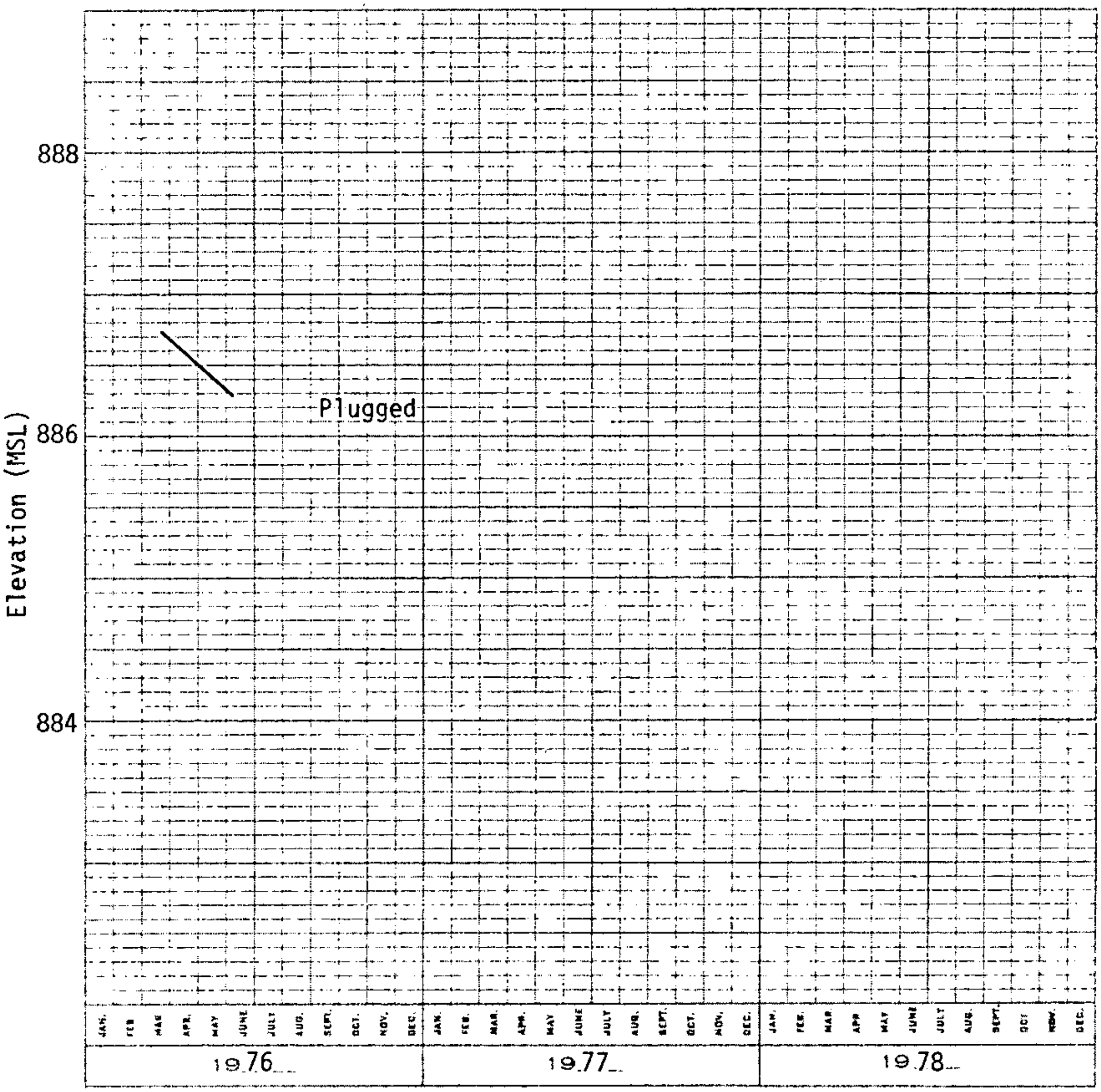


BARR ENGINEERING CO.
CONSULTING ENGINEERS

GROUND WATER HYDROGRAPH

MONITORING WELL 3

LOCATION: Northern Portion of Republic Creosote Site (middle drift aquifer)

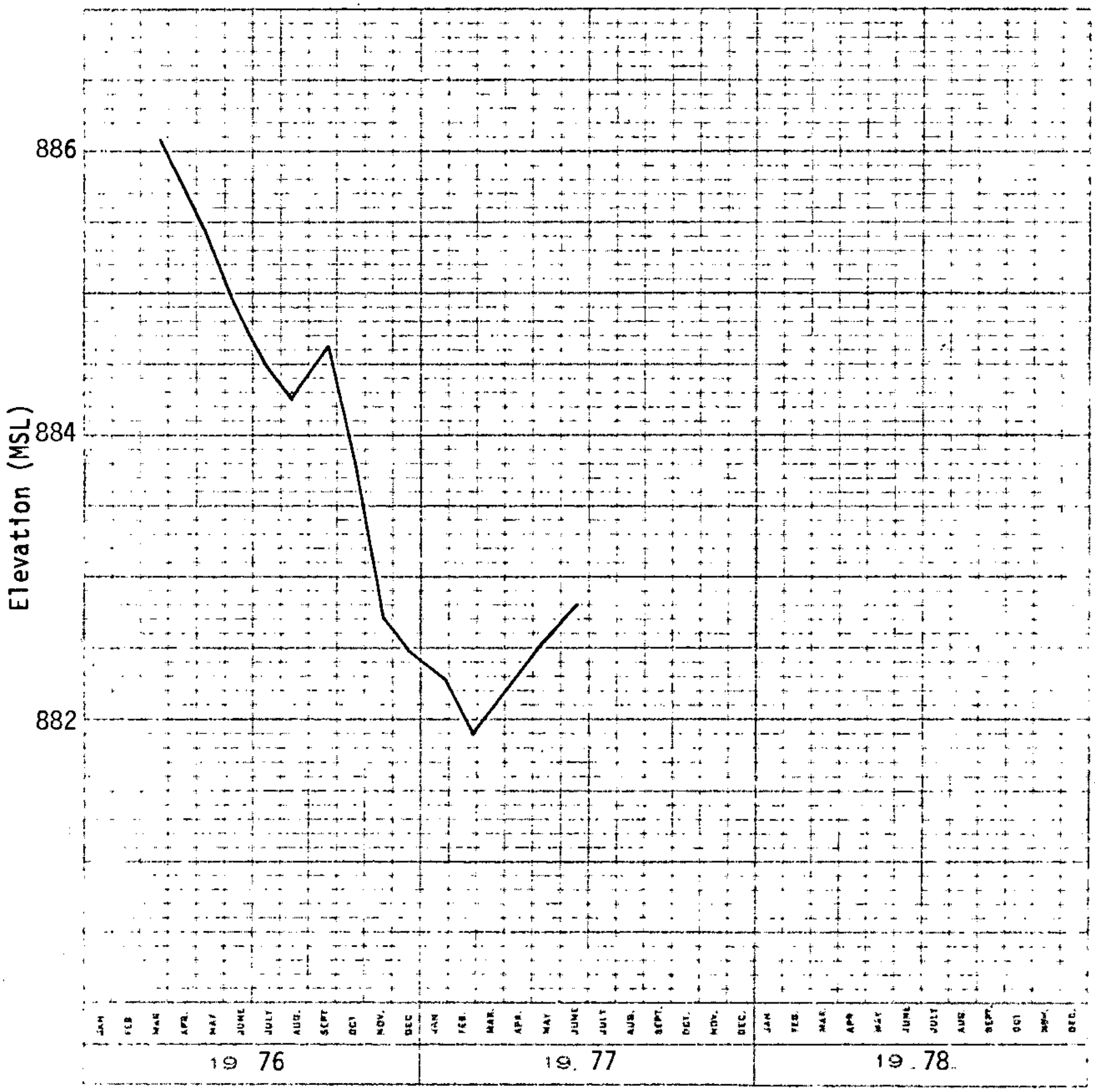


BARR ENGINEERING CO.
CONSULTING ENGINEERS

GROUND WATER HYDROGRAPH

MONITORING WELL 5

LOCATION: Southeast Portion of Republic Creosote Site (middle drift aquifer)



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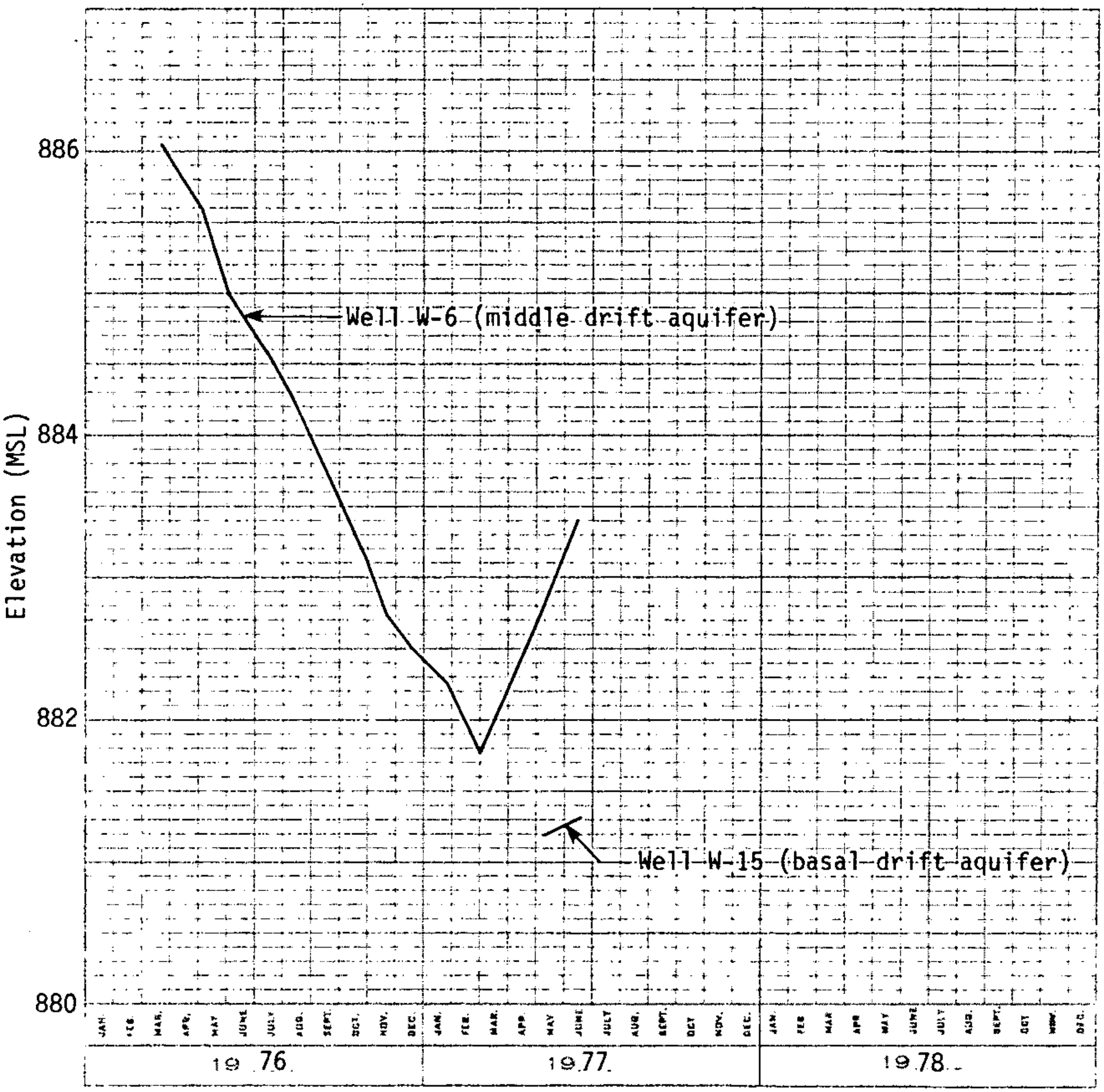
GROUND WATER HYDROGRAPH

MONITORING WELLS 6 AND 15

LOCATION: Southwest Portion of Republic Creosote Site (wells nested in middle & lower glacial drift aquifers)



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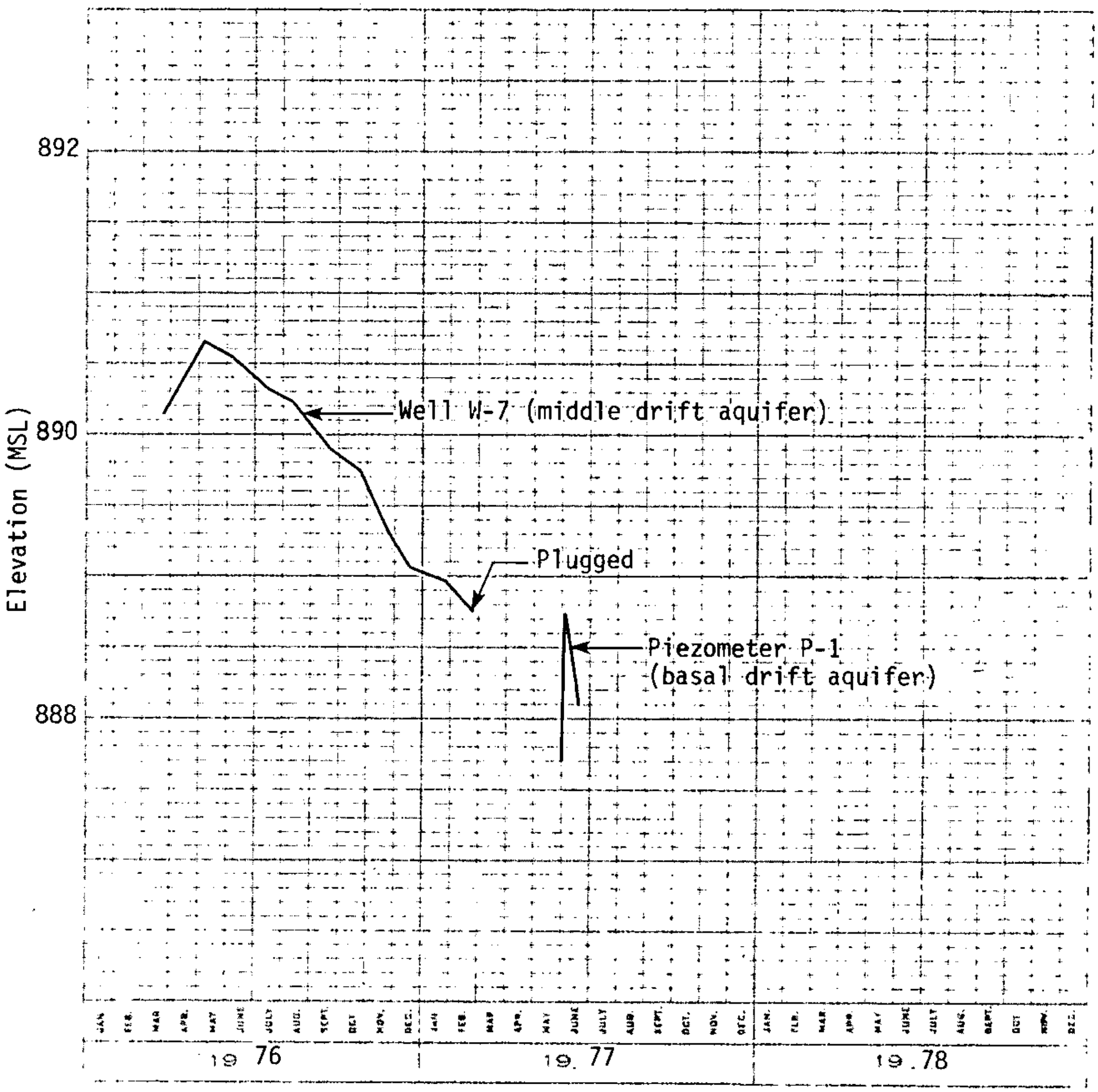
GROUND WATER HYDROGRAPH

MONITORING WELL 7 AND PIEZOMETER P-1

LOCATION: Quebec Avenue & West 35th Street
(wells nested in upper & lower
glacial drift)



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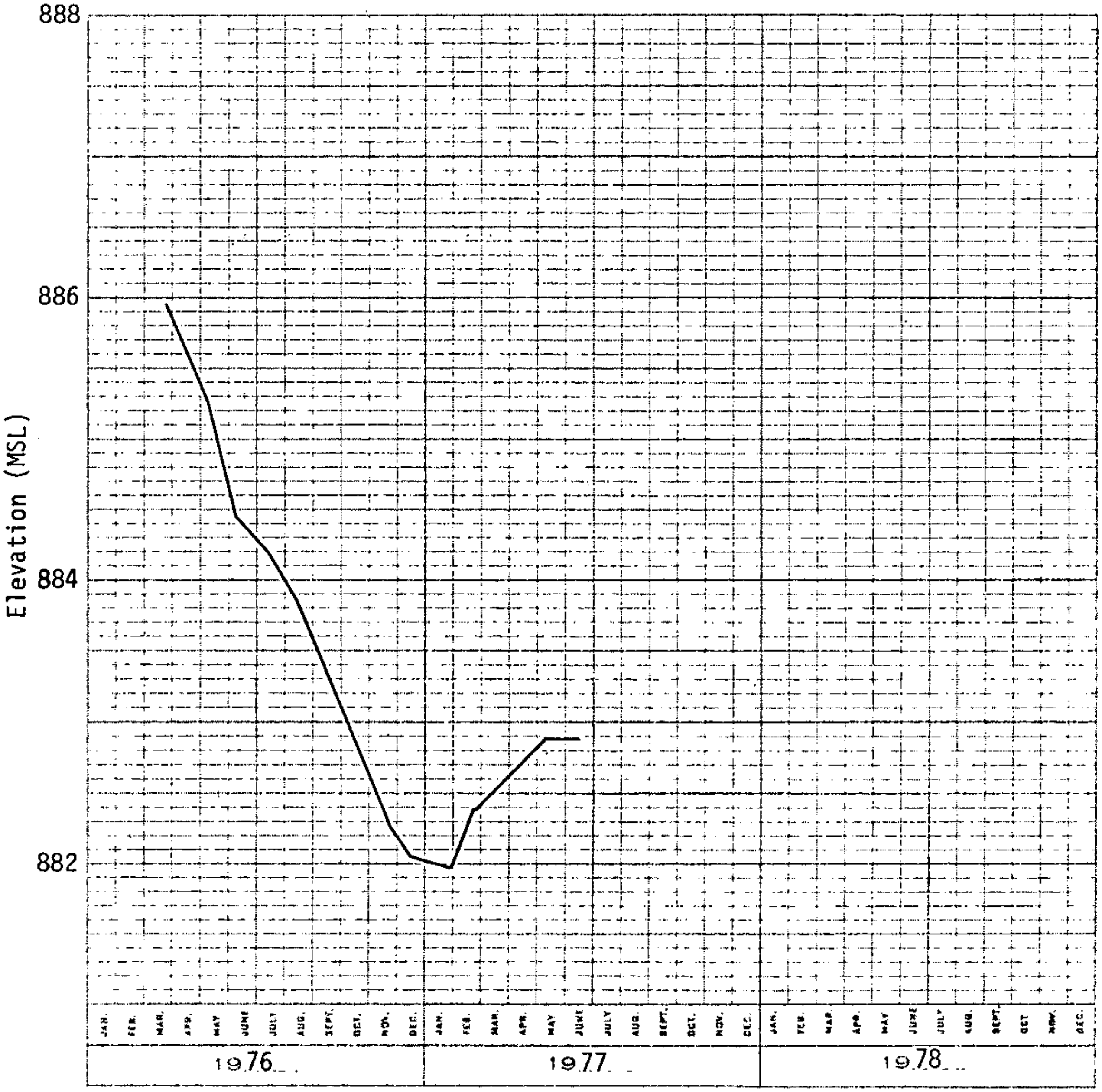
GROUND WATER HYDROGRAPH

MONITORING WELL 8

LOCATION: West Lake Street & Taft Avenue
(middle drift aquifer)



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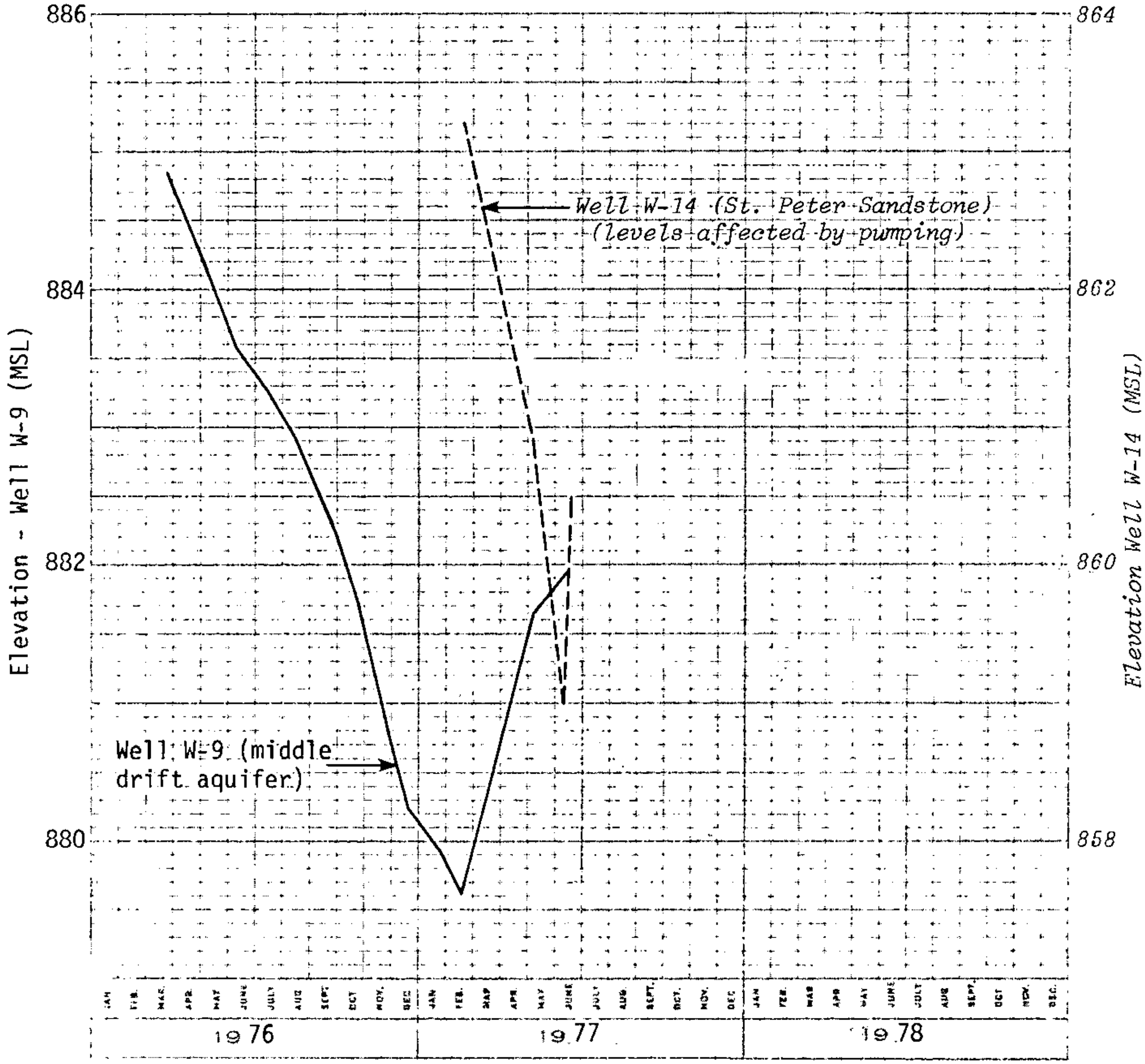
GROUND WATER HYDROGRAPH

MONITORING WELLS 9 AND 14

LOCATION: West Lake Street & Monitor Street



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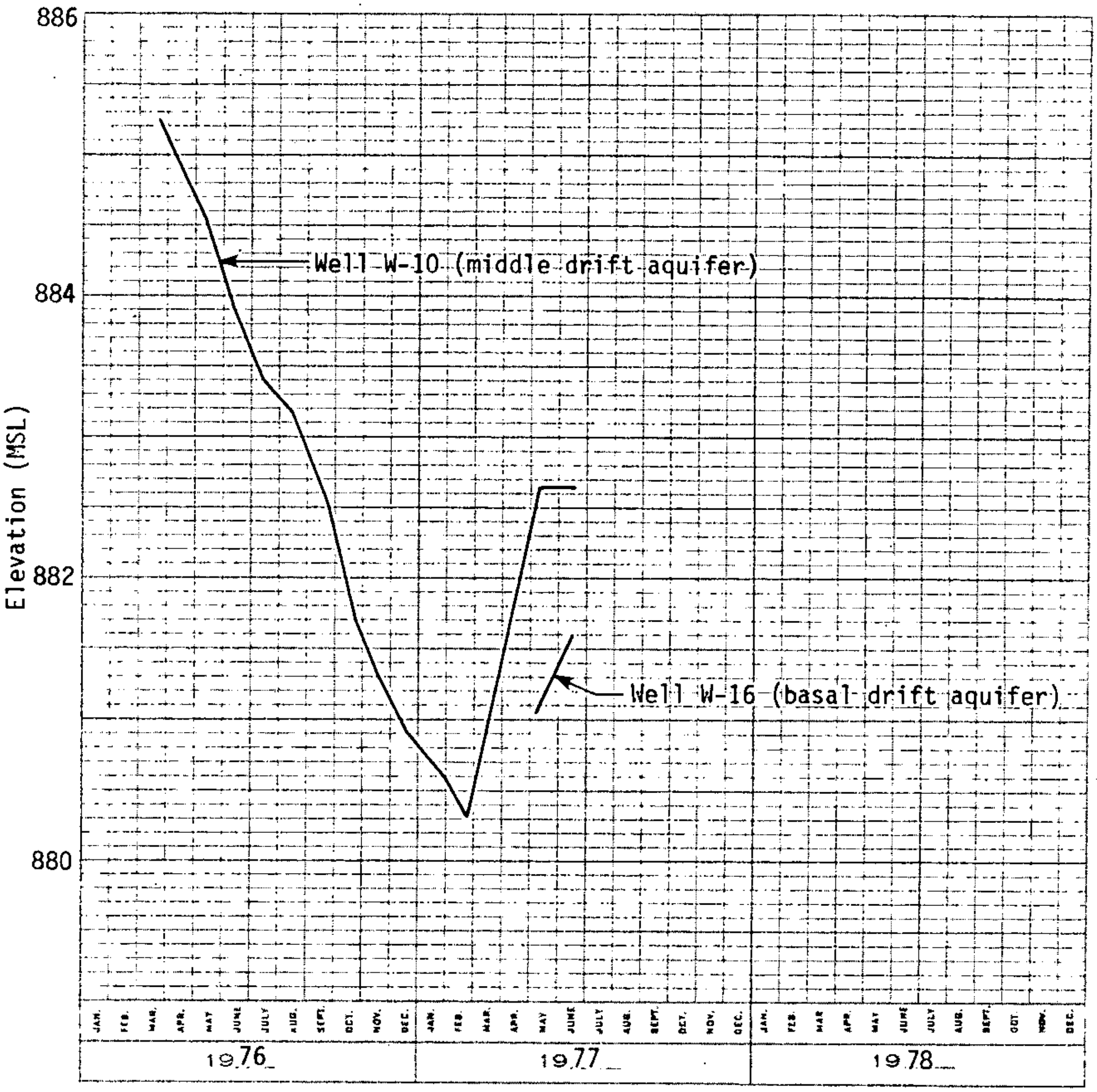
GROUND WATER HYDROGRAPH
MONITORING WELLS 10 AND 16

LOCATION: Oxford Street & Louisiana Avenue
(south of Chicago & Northwestern R.R.)



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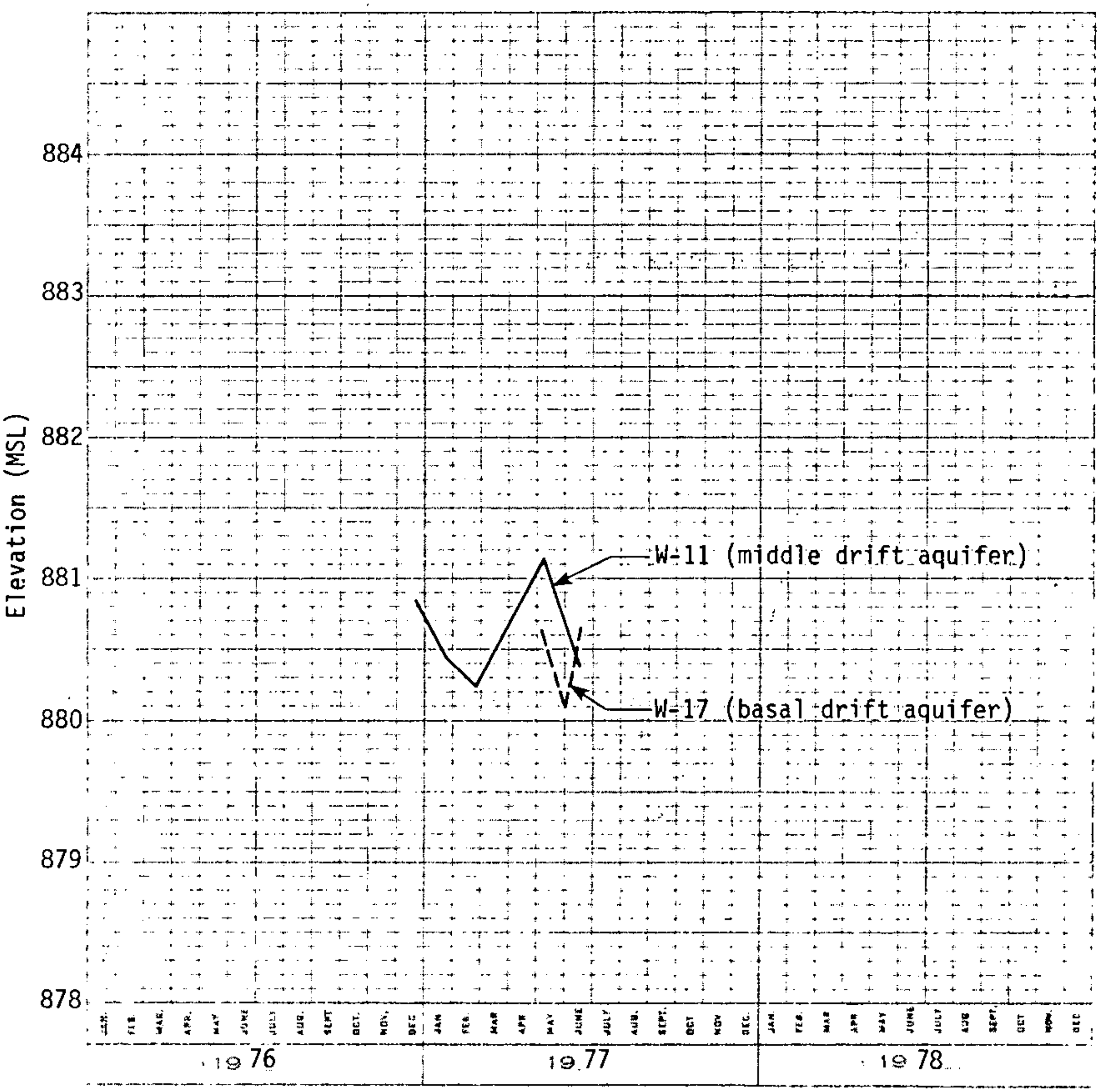
GROUND WATER HYDROGRAPH
MONITORING WELLS 11 AND 17

LOCATION: Hampshire Avenue Between T.H. 7
& Northwestern R.R.



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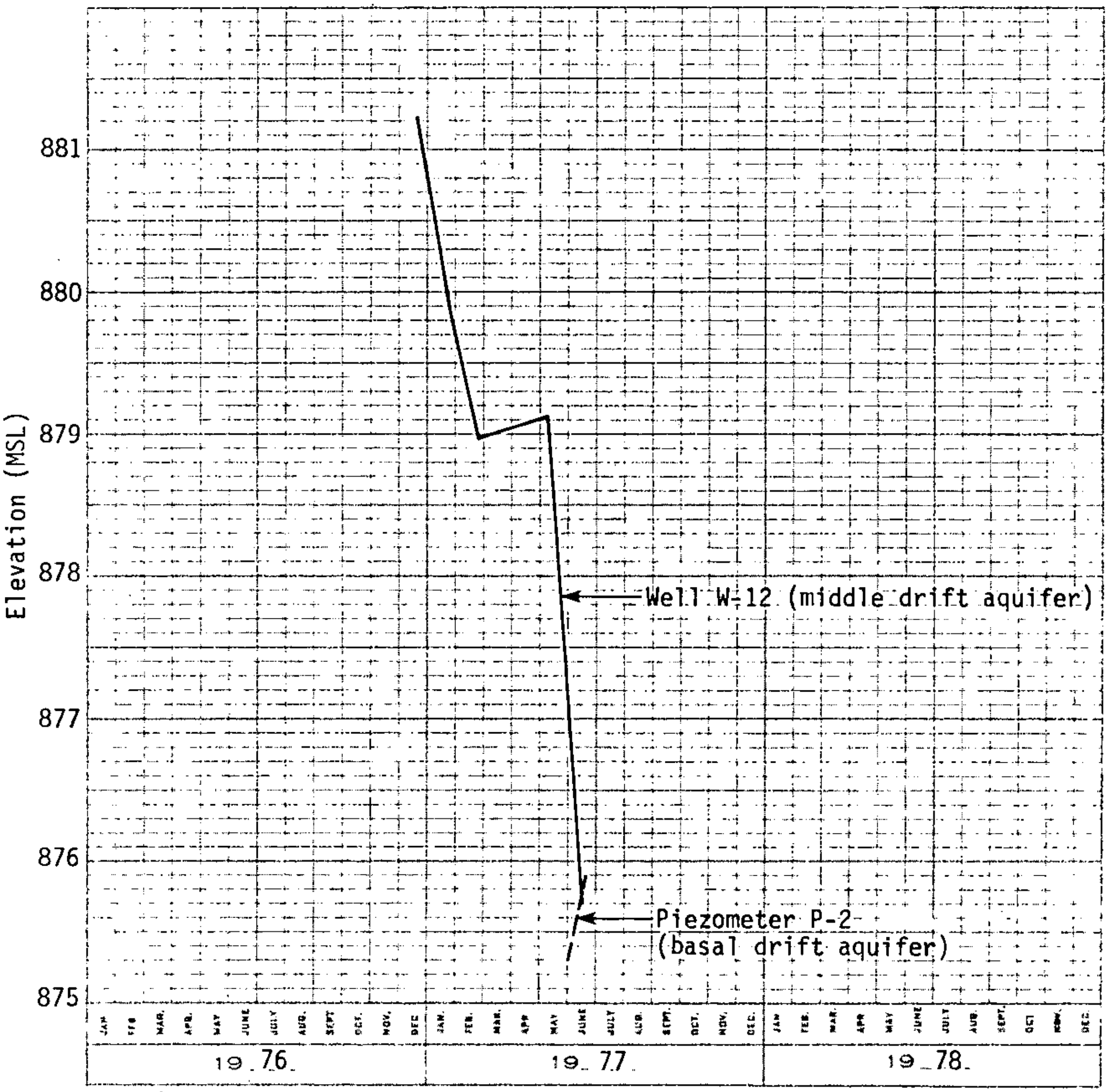
GROUND WATER HYDROGRAPH

MONITORING WELL 12 AND PIEZOMETER P-2

LOCATION: Minnesota Northfield & Southern R.R.
Between T.H. 7 & Chicago & Northwestern R.R.



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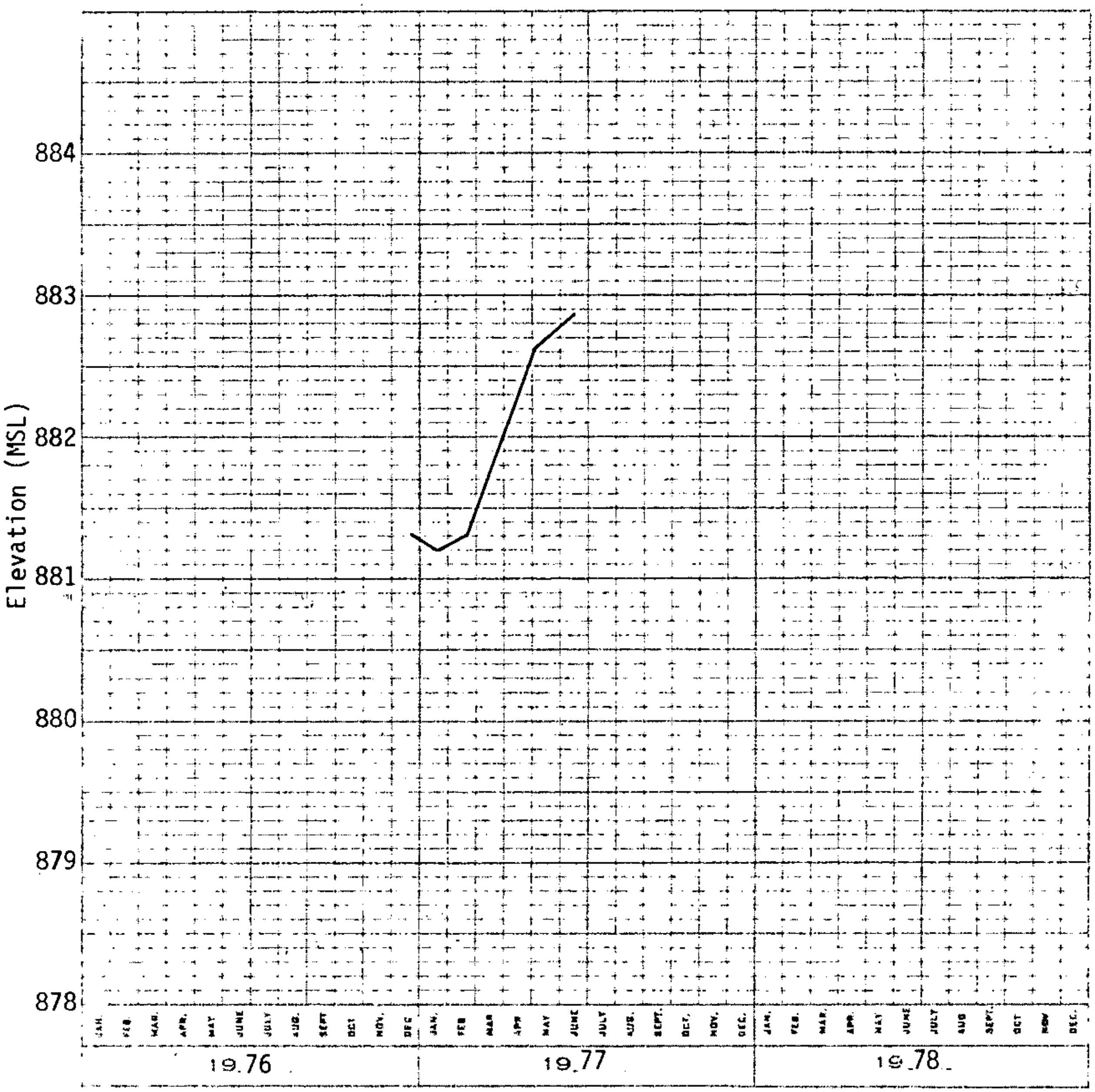
GROUND WATER HYDROGRAPH

MONITORING WELL 13

LOCATION: Wetland Between T.H. 7 & Lake Street
(middle drift aquifer)



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	#1 Benz		#1 Phen		#2 Benz	#2 Phen	#_ Benz	#_ Phenol
Dup	2300	Dup	.67		430*	<0.2	120	
Dup	6300	Dup	4.6		240	<0.2 *	158	
	230*		.73		710	<0.2	Dup 281	Dup
	600		1.1		610	<0.2	? 14	
	4~~4~~0		1.0		22	<0.2	? 816	*
	370		0-35	Dup	<1	Dup <0.2	510	
	96		0.53		480	<0.2	416*	

	#4 Benz		#4 Phenol
?	24000	24%	
Dup	590		Dup
	615		
	350		
	(Broken Flask)		
	404		
	1470*		*

#5

~~Benz Phenol~~

Preliminary Results Subject to change

SV

LOG OF TEST BORING

JOB NO. -- 120-2847 VERTICAL SCALE 1" = 6' BORING NO. 1

PROJECT

DEPTH IN FEET	DESCRIPTION OF MATERIAL / SURFACE ELEVATION	GEOLOGIC ORIGIN	N	WL	SAMPLE NO.	SAMPLE TYPE	W	D	LL/PL	Qu
	FILL, mixture of SILTY SAND and CLAYEY SAND, some gravel, brown, gray and black, frozen to 6½' (slight creosote odor)				1	SS				
9	SAND, fine to medium grained, a trace of gravel, gray, moist to 10½' then waterbearing, loose (SP) (very strong creosote odor, creosote oil noticeable in sample)		6		-	--				
			5		2	SS				
15	SAND, medium grained, some gravel, gray, waterbearing, very dense (SP) (very strong creosote odor in sample at from 17½'-18½' and 24½'-26', some odor in sample 30'-31', creosote oil noticeable in sample from 17'-18½')				3	?				
			28		4	SS				
			35		5	SS				
33	SAND, medium grained, a trace of gravel, gray, waterbearing, very dense, lenses of silty clay below (See#1)		45		6	SS				
37	SAND, medium grained, a little gravel, brown, waterbearing, dense (SP) (slight creosote odor)		25		7	SS				
	SAND, coarse grained, with gravel, cobbles and boulders, gray, waterbearing, very dense (SP-SM to GP-GM) (slight creosote odor)		47		8	SS				
	SAND, medium to coarse grained, some ravel, a few cobbles and boulders,									

Continued on next page

LOG OF TEST BORING

JOB NO. 120-2847 VERTICAL SCALE 1" = 6' BORING NO. 1 Cont.

PROJECT

DEPTH IN FEET	DESCRIPTION OF MATERIAL	GEOLOGIC ORIGIN	N	WL	SAMPLE NO.	SAMPLE TYPE	W	D	L.L./P.L.	Qu
50	brown, waterbearing, very dense (SP) (very slight creosote odor)		44		9	SS				
			48		10	SS				
			100/0.4		11	SS				
62	SAND, medium grained, a little gravel, a few cobbles and boulders, brown, waterbearing, very dense (SP-SM) (no noticeable creosote odor)		100/0.4		12	SS				
68	LIMESTONE									
69.7	End of Boring									
	#1 - about 36' (SP) (strong creosote odor)									

WATER LEVEL MEASUREMENTS

DATE	TIME	SAMPLED DEPTH	CASING DEPTH	CAVE-IN DEPTH	BAILED DEPTHS	WATER LEVEL
		12'	19½'		to	10½'
					to	
					to	
					to	

START 3-10-78 COMPLETE 3-13-78

METHOD 3¼ HSA 0' - 12' @ 12:00

4C 0' - 14½'

DM 14½' - 69.7'

CREW CHIEF Scherle

LOG OF TEST BORING

JOB NO. 120-2847 VERTICAL SCALE 1" = 6' BORING NO. 2

PROJECT

DEPTH IN FEET	DESCRIPTION OF MATERIAL / SURFACE ELEVATION	GEOLOGIC ORIGIN	N or R	WL	SAMPLE NO.	SAMPLE TYPE	W	D	LL/PL	Qu
	FILL, mixture of SANDY CLAY and MUCK, black and dark brown, frozen									
2	FILL, mostly SLUDGE, light gray, frozen to 3½'									
			2		1	SS				
8	MUCK, black, soft (Pt) (has sludge odor)									
10½	SILTY SAND, a little gravel, (See#1)		18		2	SS				
12	SAND, medium grained, a little gravel, gray, waterbearing, loose (SP) may have creosote odor		5		3	SS				
18	GRAVEL, gray, waterbearing, dense (SP) has very slight creosote odor		18		4	SS				
23	SAND, coarse grained, with gravel, gray, waterbearing, medium dense to dense (SP-GP) no creosote odor		13		5	SS				
			18		-	--				
			13		-	--				
38	GRAVEL, gray, waterbearing, dense (GP) no creosote odor		20		6	SS				
43	SAND, medium to coarse grained, some gravel, gray, waterbearing, loose, lenses of clayey sand below (See#2)		9		7	SS				
47	SAND, fine grained, a trace of gravel, brown, waterbearing, medium dense, lenses of sandy clay below about 50½'									
50										

Continued on next page

LOG OF TEST BORING

JOB NO. 120-2847 VERTICAL SCALE 1" = 6' BORING NO. 2 Cont.

PROJECT

DEPTH IN FEET	DESCRIPTION OF MATERIAL	GEOLOGIC ORIGIN	N or R	WL	SAMPLE NO.	SAMPLE TYPE	W	D	L.L. / P.L.	Qu
50			13		8	SS				
53 – 57	SAND, medium to fine grained, a little gravel, a few boulders, brown, waterbearing, very dense, (See#3)		134		9	SS				
57 – 70	SILTY SAND, medium to fine grained, some gravel, a few boulders, brown, a few lenses of waterbearing sand (SM-SP) no creosote odor		59		10	SS				
			138		11	SS				
70 – 73.9	LIMESTONE, light gray and gray mottled, 0.2' badly weathered zone from about 71' - 71.2'	PLATTEVILLE FORMATION Mifflin Member	90%			BX				
73.9	End of Boring									

#1 - gray, wet, medium dense (SM) has sludge odor

#2 - about 46' (SP) has slight creosote odor

#3 - a few lenses of silty sand (SP-SM) no creosote odor

R = percent of core recovery

WATER LEVEL MEASUREMENTS

DATE	TIME	SAMPLED DEPTH	CASING DEPTH	CAVE-IN DEPTH	BAILED DEPTHS	WATER LEVEL
3-13		16'	14½'		to	12'
					to	
					to	
					to	

START 3-13-78 COMPLETE 3-13-78 @ 2:30

METHOD 3¼ HSA 0' - 14½'

4C 0'-14½', NWC 0'-70, DM 17'-

BX diamond bit 70' - 73.9'

CREW CHIEF Scherle

LOG OF TEST BORING

JOB NO. 120-2847 VERTICAL SCALE 1" = 6' BORING NO. 3

PROJECT

DEPTH IN FEET	DESCRIPTION OF MATERIAL / SURFACE ELEVATION	GEOLOGIC ORIGIN	N	WL	SAMPLE NO.	SAMPLE TYPE	LABORATORY TESTS W	D	LL / PL	Qu
	No samples taken.									
5	FILL, mostly SLUDGE, light gray				1	SS				
7	PEAT, dark brown, moist (Pt)				2	SS				
9	ORGANIC SILTY CLAY, black to dark grayish brown									
10½	SILTY CLAY, gray, soft (CL) (no odor)		3		3	SS				
12½	SAND, medium to coarse grained, with gravel, gray, waterbearing, medium to dense (SP) (strong creosote odor from 15½' - 17', slight odor from 20½' - 22', no odor from 30' - 31½')		13		4	SS				
			12		5	SS				
			18		6	SS				
33	CLAYEY SAND, a little gravel, gray and brown mottled, very stiff (SC) (possibly slight creosote odor)		56		7	SS				
36	SAND, medium grained, a little gravel, gray, waterbearing, medium dense (SP) (no creosote odor)		10		8	SS				
48	SAND, fine to medium grained, gray, waterbearing, medium dense (SP)									
50	Continued on next page									

LOG OF TEST BORING

JOB NO. 120-2847 VERTICAL SCALE 1" = 6' BORING NO 3 Cont.

PROJECT

DEPTH IN FEET	DESCRIPTION OF MATERIAL	GEOLOGIC ORIGIN	N	WL	SAMPLE NO.	SAMPLE TYPE	W	D	L.L./P.L.	Qu
50			14		9	SS				
53½	SAND, coarse grained, with gravel, gray, waterbearing, dense, lenses of sandy clay and clayey sand (See#1)		16		10	SS				
57	SAND, medium grained, some gravel, brown, waterbearing, medium dense (SP) (no creosote odor)		10		11	SS				
63	SILTY SAND, some gravel, brown, wet, very dense, lenses of waterbearing, sand (SM) (possibly slight creosote odor)		41		12	SS				
71	Pieces of LIMESTONE, a little (See#2)				13	SS				
71.5	Obstruction									

#1 - below about 56' (SP)

#2 - gravel, gray, wet (GP-GM)

WATER LEVEL MEASUREMENTS

DATE	TIME	SAMPLED DEPTH	CASING DEPTH	CAVE-IN DEPTH	BAILED DEPTHS	WATER LEVEL
					to	
					to	
					to	
					to	

START 3-16-78 COMPLETE 3-17-78

METHOD 3¼ HSA 0' - 9½' @ 10:10

4C 0' - 15'

DM 15' - 71½'

CREW CHIEF Scherle

LOG OF TEST BORING

JOB NO. 120-2847 VERTICAL SCALE 1" = 6' BORING NO. 4

PROJECT

DEPTH IN FEET	DESCRIPTION OF MATERIAL / SURFACE ELEVATION	GEOLOGIC ORIGIN	N	WL	SAMPLE NO.	SAMPLE TYPE	W	D	LL/PL	Qu
	No samples taken.									
5½	PEAT, dark brown, moist (Pt)		5		1	SS				
7	SILTY SAND, medium to coarse grained, with gravel, dark gray to gray, wet, very dense (SM)		61	▼	2	SS				
11½	SAND, medium grained, a little gravel, gray, waterbearing, dense (SP) (no creosote odor)		19		3	SS				
18	SAND, medium to fine grained, a little gravel, gray, waterbearing, medium dense (SP) (no creosote odor)		11		4	SS				
23	SAND, medium grained, a little gravel, gray, waterbearing, dense to medium dense (SP) (no creosote odor)		17		5	SS				
			12		6	SS				
33	SAND, fine to medium grained, a trace of gravel, gray, waterbearing, medium dense (SP)		13		7	SS				
40	SILTY SAND, a little gravel, brown, wet, very dense, some lenses of clayey sand and waterbearing sand (SM)		22		8	SS				
43	SAND, medium grained, a little gravel, brown, waterbearing, a few lenses of clayey sand and silty (See#1)		45		9	SS				
47	SILTY SAND, medium to fine grained, some gravel, a few cobbles and limestone slabs from 58½'-61½', (See#2)									
50										

Continued on next page

LOG OF TEST BORING

JOB NO. 120-2847 VERTICAL SCALE 1" = 6' BORING NO. 4 Cont.

PROJECT

DEPTH IN FEET	DESCRIPTION OF MATERIAL	GEOLOGIC ORIGIN	N	WL	SAMPLE NO.	SAMPLE TYPE	LABORATORY TESTS W	D	L.L./P.L.	Qu
50			50		10	SS				
			24		11	SS				
			98		12	SS				
65			100/0.1		-	--				
	LIMESTONE, gray									
69.5	End of Boring									

#1 - sand (SP-SM)

#2 - brown, waterbearing, very dense, lenses of sand (SM-SP)

*No measurement recorded due to presence of drilling fluid.

WATER LEVEL MEASUREMENTS

DATE	TIME	SAMPLED DEPTH	CASING DEPTH	CAVE-IN DEPTH	BAILED DEPTHS	WATER LEVEL
3-17	3:00	17'	None		to	10½'
3-18	11:30	69.5'	15'		to	*
3-18	12:00	69.5'	None		to	*
					to	

START 3-17-78 COMPLETE 3-18-78

METHOD 4C 0' - 15' @ 11:30

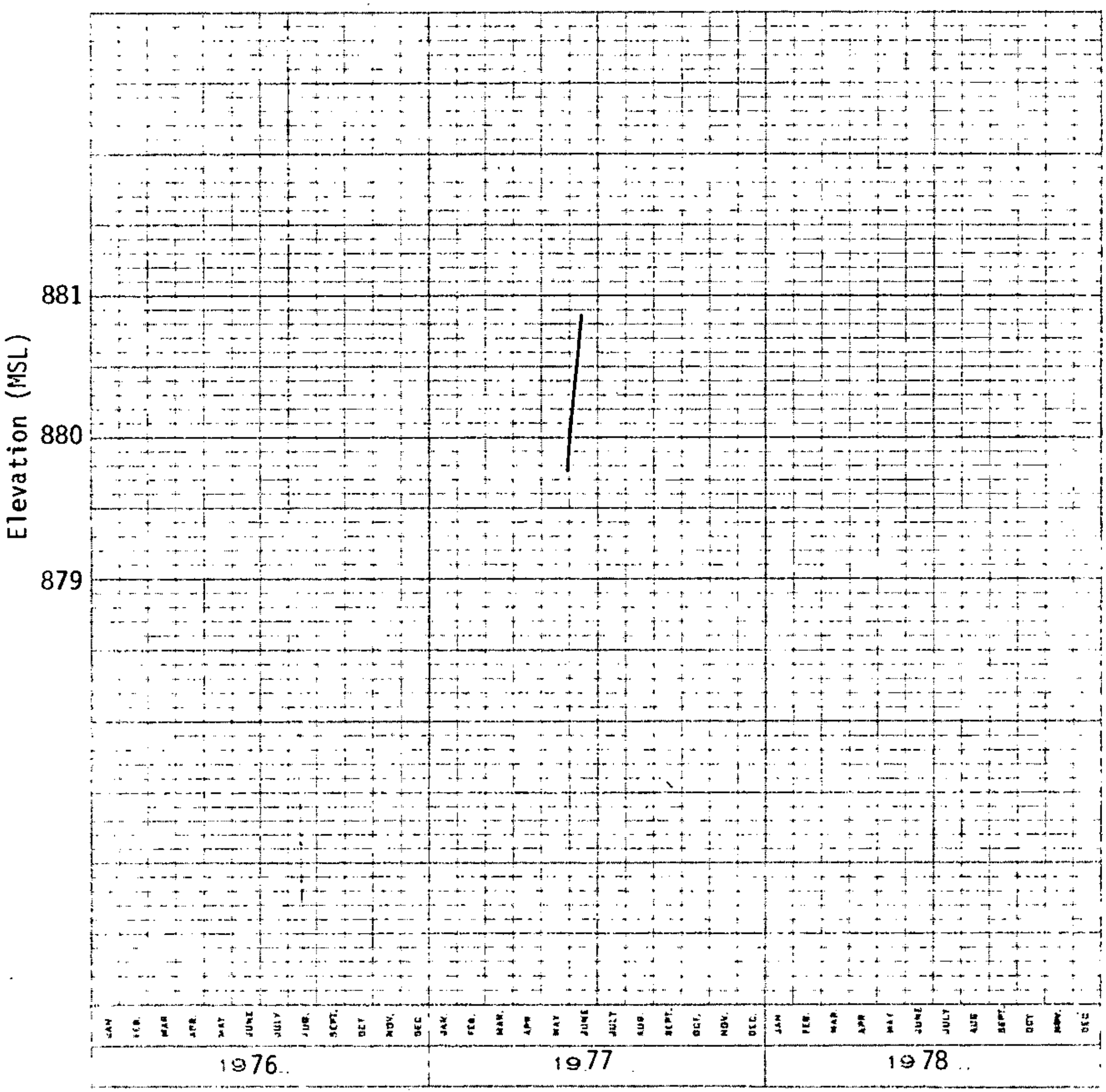
JW 0' - 30

DM

CREW CHIEF Scherle

GROUND WATER HYDROGRAPH
PIEZOMETER 17

LOCATION: Louisiana Avenue & South Street
(lower drift aquifer)



BARR ENGINEERING CO.
CONSULTING ENGINEERS

APPENDIX C

ANALYTICAL TECHNIQUES USED BY SERCO LABORATORIES

ANALYTICAL METHODS
SERCO LABORATORIES

Parameter	Method	Detection Limit	Reference
Alkalinity	Potentiometric	1 mg/l as $CaCO_3$	Page 278 - Standard Methods(2)
Copper	Atomic Absorption	0.05 mg/l	Page 108 - EPA(3)
Lead	Atomic Absorption	0.1 mg/l	Page 112 - EPA(3)
Grease & Oil	Trichlorotrifluorethane	1 mg/l	Page 229 - EPA(3)
Total Hardness	EDTA, Titrimetric	2 mg/l	Page 202 - Standard Methods(2)
Arsenic	Atomic Absorption-Graphite Furnace	1 μg/l	Perkin Elmer Manual(1)
Specific Conductance	Wheatstone Bridge	10 μmho/cm	Page 71 - Standard Methods(2)
Total Dissolved Solids	Total Solids-Filterable Solids	1 mg/l	Page 93 & 294 - Standard Methods(2)
Total Organic Carbon	Combustion-FID Method	1 mg/l	Page 236 - EPA(2)
Biochemical Oxygen Demand	Probe	1 mg/l	Page 543 - Standard Methods(2)
Chemical Oxygen Demand	Dichromate Reflux, Titrimetric	4 mg/l	Page 550 - Standard Methods(2)
pH	Glass, Electrode	± 0.1 Unit	Page 460 - Standard Methods(2)
Phenolics	Chloroform Extraction, Colorimetric	0.002 mg/l	Page 576 - Standard Methods(2)
Zinc	Atomic Absorption-Direct Aspiration	0.01 mg/l	Page 155 - EPA(3)

1. Perkin-Elmer Corporation, Sept. 1973, Analytical Methods for Atomic Absorption Spectroscopy Using the HGA Graphite Furnace, Perkin-Elmer, Norwalk, Connecticut, USA.
2. APHA, AWWA, WPCF, 1976, Standard Methods for the Examination of Water and Wastewater, 14th Edition, American Public Health Association, 1015 Eighteenth Street N.W., Washington, D. C. 20036.
3. U.S. EPA, 1974 Methods for Chemical Analysis of Water and Wastes, EPA-625-/6-74-003, U.S. Environmental Protection Agency, Office of Technology Transfer, Washington, D. C. 20460.

APPENDIX D

EPA LABORATORY REPORTS

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

SUBJECT: Analytical Results of Samples 77-15944 through 77-15947

DATE: March 18, 1977

FROM: Curtis Ross
Director, Central Regional Laboratory

CR

TO: Director
Minn.-Wisconsin District Office

This is to inform you that the Central Regional Laboratory has completed the analysis of subject samples. (See attachment for sample description.)

Analysis involved extraction of the aqueous sample three times (each time with 60 ml of a 15% methylene chlorine/hexane solution). The extracts were then combined and concentrated to approximately 1 ml. Appropriate amounts of the concentrated extracts were then injected into a gas chromatograph.

The results of the analysis are as follows:

1. Samples 77-15945 and 77-15946 contained no detectable organics (detection limit 10-50 ppb).

2. Sample 77-15944 contained what appeared to be a residual fuel oil at a concentration of approximately 4 grams oil/liter of water.

3. Sample 77-15947 contained a complex mixture of light hydrocarbons somewhat similar to gasoline. The exact concentration cannot be determined, but we estimate the approximate concentration to be 50-500 ppm for each component of the mixture.

Please call Dr. Emilio Sturino (FTS 353-8370) if you have any questions regarding these analyses.

Attach.

cc: J. Harrison, Water Division
Water Supply Branch

Note: The concentration shown in # 2 above was ~~obtain~~ extracting and weighing the residue. CR

EPA Form 1320-6 (Rev. 6-72)

UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY
REGION V
CENTRAL REGIONAL LABORATORY
1819 W. PERSHING RD.
CHICAGO, ILLINOIS 60609

April 26, 1977

Mr. Roman Koch
Minnesota Department of Health
Division of Environmental Health
717 Delaware South Court
Minneapolis, Minnesota 55440

Dear Mr. Koch:

Pursuant to our telephone conversation two weeks ago, the sample extract from Well #13, St. Louis Park, was re-analyzed specifically for the objectives you specified to me. The results of the analysis (using gas chromatography.mass spectroscopy) revealed that over 50% of the sample extract consists of polynuclear aromatic hydrocarbons.

Some of the compounds tentatively identified are as follows:

naphthalene*	acenaphthene
pyrene*	dibenzofuran
anthracene or phenanthrene*1	fluorine
fluoranthrene*	benzophenanthene
methyl naphthalenes	benzofluoranthene

The CRL could have saved considerable time and provided an analysis more consistent with your needs for all the samples submitted if a brief memo had been included with the samples outlining your objectives, history of the samples, and whom to contact for questions. We would appreciate it very much if this is done for future requests.

If you have any questions regarding the re-analysis or any other subject matter, do not hesitate to call me (FTS 8-353-8370).

*These compounds are present in higher concentrations relative to the others.
*1 We could not differentiate between the two.

Sincerely,

Emilio Sturino

Emilio Sturino, Ph.D.
Chief, Organic Section

Analytical Results: Samples From
St. Louis Park, Minnesota
(Samples Received May 31, 1977)

Emilio Sturino, Ph.D.
Chief, Organic Laboratory Section
U.S. Environmental Protection Agency
Region V, Central Regional Laboratory
1819 West Pershing Road
Chicago, IL 60609
312-353-8370

Objective

To provide a comprehensive organic analysis of six groundwater samples. The results of the analysis are to be used to monitor the movement of organics from one well throughout the groundwater shed at St. Louis Park, Minnesota.

Results

The quantitative results of the analysis are summarized in Table I.

Table I

Quantitative Summary of Data

CRL Sample #	Well #	Concentration mg/l Polynuclear Aromatics	Total Extractables
77-18465	W-9	<0.1	2.5
77-18466	W-13	3,400	3,400
77-18467	W-14	<0.03	0.05
77-18468	W-17	1.7	1.7
77-18469	CW-3	<0.03	0.05
77-18470	Flame	<0.03	0.05

Qualitative results indicate that sample #77-18466 contains the following polynuclear aromatic hydrocarbons:

- naphthalene
- methylnaphthalene
- acenaphthene
- dibenzofuran
- phenanthrene or anthracene
- fluoranthene
- pyrene

Naphthalene and acenaphthene were also detected in sample #77-18468. No detectable amounts of polynuclear aromatic hydrocarbons were detected in samples 77-18469 and 77-18470. Sample 77-18465 contains a mixture of hydrocarbons but no polynuclear aromatic hydrocarbons could be detected.

Analytical Procedure

Each sample was extracted three times, once each with 60 ml of 15% (V/V) methylene chloride in hexane. The combined extracts were then concentrated to approximately one ml on a steam bath using a Kuderna-Danish apparatus. The concentrated extracts were then analyzed by flame-ionization gas chromatography and by computerized gas chromatography mass spectroscopy.

The analytical column used consisted of a 6' x 1/8" glass column packed with 5% Dexil 300 on ABS Anakron. The column oven temperature was programmed from 100° to 300°C at 10° per minute.

After glass chromatographic analysis, the samples were concentrated to constant weight at room temperature by means of a gentle stream of nitrogen. The results are reported as total extractables.

Participants

All sample preparation and analytical work was performed by Dr. Emilio Sturino and Mr. Robert Glowacky.

APPENDIX E

THE DIFFICULTY IN USING PUMPING TESTS TO DEFINE THE VERTICAL PERMEABILITY OF THE GLENWOOD SHALE

APPENDIX E

THE DIFFICULTY IN USING PUMPING TESTS TO DEFINE THE VERTICAL PERMEABILITY OF THE GLENWOOD SHALE

Initially, the vertical permeability of the Glenwood aquitard was to be determined using pumping tests. Traditionally, this has been carried out by the Hantush Modified Method which assumes that a confined aquifer is overlain and underlain by aquitards. Input data to the method are the time rate of drawdown from two wells; one pumping well fully penetrating and screened through the aquifer and one observation well in the aquifer. Before installing the necessary test wells for this study, calculations were carried out using the following assumed aquifer characteristics to test the sensitivity of data generated by the pumping tests.

a. Platteville Limestone
   - permeability, $K_{Op} = \infty$ cm/sec

b. Glenwood Shale
   - permeability, $k' =$ variable, but assumed equal to 10^{-8} cm/sec initially
   - thickness, $b' = 1$ meter
   - specific storage, $S_s' = 10^{-5}$ cm^{-1}

c. St. Peter Sandstone
   - permeability, $k = 5 \times 10^{-3}$ cm/sec
   - thickness, $b = 33.5$ meters
   - specific storage, $S_s = 3.3 \times 10^{-8}$ cm^{-1}
   - storage coefficient, $S = 1.1 \times 10^{-4}$

d. 10 m distance between the pumping and observation wells

e. The base of the St. Peter is impermeable

f. The pumping well is fully screened and fully penetrates the St. Peter.

These values were used in the equations given in Lohman (1972). The resulting beta (β) equaled 1.8×10^{-3}. Since β must be two orders of magnitude greater (10^{-1}) to begin to detect leakage, leakage could not be detected under these conditions. The distance to the observation well in the St. Peter could be increased so that β would equal .1. However, $H(u,\beta)$ would still be almost identical to $W(u)$, indicating non-leaky conditions. Leakage could be more effectively detected by increasing the pumping time; however, increasing the duration of the test would increase the interference from background fluctuations in the St. Peter. Because of the extensive use of the St. Peter by various industrial and municipal wells in the vicinity of the study area, fluctuations in the piezometric level of the St. Peter of several feet in a matter of hours have been measured.

In addition, the following factors directly influence the suitability of using pumping tests to estimate vertical leakage through the Glenwood.

1. The pumping rate would have to be high to influence an observation well at the distance that was found to be necessary to detect leakage. Since the St. Peter could not be fully screened within the budget available for this portion of the study, the pumping rate would have had to be further increased.

2. There is no aquiclude underlying the St. Peter, but rather an aquitard that is likely more leaky than the Glenwood. It is conceivable that most of the "leakage" that would be observed entering the St. Peter could come from upward flow from the underlying aquifer.

A second approach was used to evaluate the suitability of the Hantush Modified Method. The magnitudes of expected background piezometric level fluctuations were estimated for pumping tests of various durations. These fluctuations, s_n, were estimated to be 0.2 meter for a 3-hour test, 1.3 meters for a 1-day test, 3.0 meters for a 1-week test, and 5.0 meters for a 1-month test. If these background fluctuations were superimposed upon the theoretical drawdown, s_t, for a given $k'S_s'$, called $k'S_s'{}_t$ so that the observed drawdown, s_o, was $s_o = s_t \pm 1/2\ s_n$, the values of

$k'S_s'$ that correspond to the two values for s_o, called $k'S_s'{}_o$, will give an idea of the range of values for $k'S_s'$ that can be derived from drawdown curves drawn within this background fluctuation. The wider the range of respective $k'S_s'{}_o$ values, the more sensitive that pumping test and those assumed aquifer conditions are to background fluctuations and the less acceptable are the results for estimating vertical leakage through the Platteville. This approach was applied to pumping tests conducted at 100 gallons per minute with the distance between pumping and observation wells, r, of either 100 meters or 10 meters, $k'S_s'{}_t$ was assumed to vary from 10^{-9} to 10^{-6} sec^{-1}.

For the calculated pumping tests conducted with r = 100 meters, the range of $k'S_s'{}_o$ was very large. The 1-week and 1-month pumping tests had an infinite range in $k'S_s'{}_o$ possible for each value of $k'S_s'{}_t$. The 1-day test had a $k'S_s'{}_o$ range of 10^5 for $k'S_s'{}_t$ values of 10^{-12} to 10^{-15} with the rest of the values having an infinite range. It was, therefore, concluded that for r = 100 meters, the Hantush Modified Method was too sensitive to background fluctuations and the data could not be used to measure vertical movement through the Glenwood.

For a well spacing of 10 meters, a pumping test can be conducted for a maximum of only 3.2 hours. Thereafter, the values for the β type curves have not been computed and the type curves themselves had not been drawn in both Lohman (1972) and Hantush (1970). These values could be computed, but there is the additional difficulty that these portions of the type curves are almost horizontal and are practically indistinguishable from the Theis (β = 0) curve. The ranges of $k'S_s'{}_o$ for each $k'S_s'{}_t$ is small and rather insensitive to background fluctuations, the $k'S_s'{}_o$ ranges varying by an order of 5 to 100 times for values of $k'S_s'{}_t$ from 10^{-9} to 10^{-14}. Lower values of $k'S_s'{}_t$ had an infinite range for $k'S_s'{}_o$. Therefore, theoretically for r = 10 meters $k'S_s'$ could be determined down to a value of 10^{-4} sec^{-1}.

However, there are two drawbacks to this test:

1. For the range of values for $k'S_s'{}_t$ that are reasonable, $10^{-11} \le k'S_s'{}_t \le 10^{-15}$, the corresponding data curves are

almost identical to the Theis curve ($\beta = 0$), especially since any plot of drawdown versus time would involve only the last three log cycles of the type curve. The curves are almost flat and it would be very difficult to tell them apart.

2. The frequencies of the cycles creating the background fluctuations in the pumping are on the order of 3 hours or longer. The drawdown curve could appear smooth and lacking background interference while actually experiencing a slow drop or increase in piezometric level from background interference, yielding an erroneous estimate of $k'S_s'$.

A further reduction in the distance between the pumping and observation wells would only increase these problems. For these reasons, it was concluded that the Hantush Modified Method could only measure vertical permeability on the order of 10^{-7} cm/sec and, therefore, was not very useful for estimating vertical movement through the Glenwood.

A method developed by Neuman and Witherspoon (California Department of Water Resources, 1971) was also investigated to determine the vertical permeability of the aquitard. In this method, the pumping well is located in the St. Peter and two observation wells are used; one in the St. Peter and one in the Glenwood. To assess the effectiveness of this method for determining the vertical leakage through the Glenwood, calculations were again made using the same assumed parameters used in the first approach to the Hantush Modified Method.

In order for the assumed leakage to be detected using this method, the necessary duration of pumping test was found to be at least 4.8 days at a rate of 100 gallons per minute (gpm). Resulting drawdown in the Glenwood observation well would be 3.5 mm, a barely detectable change.

The ratio of the vertical permeability to the specific storage of the Glenwood, k'/S_s', is important for assessing the effectiveness of this method. For ratios less than or equal to 0.01, the drawdown in the Glenwood would be undetectable for pumping periods of up to several weeks. If the ratio is 0.1, a drawdown would be detectable within a day. For the assumed storage coefficient and pumping rate, the drawdown in the Glenwood observation well after 2-1/2 hours would be 2.1 mm, a barely detectable change. Also, that would mean that the vertical permeability in the Glenwood would be on the order of 10^{-6} cm/sec which is known to be too large.

With the assumed specific storage, there is a relationship between the vertical permeability and the duration of pumping needed to obtain a detectable drawdown in the Glenwood observation well. This relationship is

$$k' = \frac{1.4 \times 10^{-6}}{t}$$

where: k' = vertical permeability through the Glenwood, in cm/sec
t = duration of test, in hours

Therefore, if the permeability is on the order of the assumed value of 10^{-8} cm/sec, the pumping test would have to be conducted for 5.8 days before the drawdown in the Glenwood observation well could be detected. As might be expected, this method exhibits many of the same complications shown by the Hantush Modified Method. The vertical permeability of the Glenwood could not, therefore, be determined using the Neuman and Witherspoon Method for vertical permeabilities in the Glenwood less than about 10^{-6} to 10^{-7} cm/sec.

REFERENCES

Hantush, M. S. (1960) Modification of the Theory of Leaky Aquifers: J. Geophys. Res., 65 (11), 3713-3725.

Lohman, S. W. (1972) Ground Water Hydraulics: U. S. Geol. Surv. Prof. Paper 708.

Neuman and Witherspoon (California Dept. of Water Resources, 1971) Sea-water Intrusion: Aquitards in the Coastal Ground Water Basin of Oxvard Plain, Ventura County: California Dept. of Water Resources Bulletin No. 63-4.

A P P E N D I X   F

TREATABILITY OF COAL-TAR DERIVATIVES IN EFFLUENT FROM GRADIENT CONTROL WELLS

APPENDIX F

TREATABILITY OF COAL-TAR DERIVATIVES IN EFFLUENT FROM GRADIENT CONTROL WELLS

Due to regulatory constraints, the water quality parameters of most interest in the discharge from the ground water gradient control wells include phenolic substances, polynuclear aromatic hydrocarbons, chemical oxygen demand, and oil and grease. Concentrations of these organic parameters can be reduced by a variety of physical, chemical and biochemical processes which are described in the literature. In this appendix, some of these processes are briefly described. The results of laboratory tests undertaken to investigate the feasibility of several simple treatment operations are also presented.

Physical Treatment

Gravity separation, the simplest form of physically removing oily material from water, is comparable to primary treatment of wastewater in conventional sewage treatment plants. This approach is often successful, especially where oily wastes are highly concentrated, and can result in removal of a variety of organic and oxygen-demanding substances and in recovering economically useful materials. However, it has been observed that hydrocarbon mixtures in effluent from the gradient control wells will not separate readily, either because of a highly emulsified condition or because of interaction with soluble organic material, such as phenols. Upon standing for periods in excess of 24 hours, a degree of separation did occur among samples from Well 13, with a heavier dark brown sludge settling below a tan to brown supernatant. However, the sludge fraction still contained a significant amount of water. Therefore, it is likely that gravity separation processes are not feasible for efficient removal of organic materials from the effluent. Thus, if physical treatment is to be useful, more sophisticated technology must be introduced. Flotation, filtration and coagulation processes have been successful in separating oil/water emulsions (Patterson, 1975; Reynolds and Shack, 1976).

Preliminary tests, which will be described in more detail in the discussion of chemical treatment, indicated that partial chemical oxidation and coagulation successfully broke the emulsions to produce a heavy sludge, leaving a reasonably clear supernatant. Other methods of physical treatment--such as volatilization, flotation, filtration and centrifugation--were not examined.

Chemical Treatment

A variety of chemical oxidants and coagulants are available that will participate in chemical reactions to remove oily or emulsified organics from wastewater by oxidation and/or coagulation. Oxidants such as chlorine, hypochlorite, chlorine dioxide, ozone, and potassium permanganate have been used successfully in pilot and plant scale operations for the removal of phenolic and other organics (Armco et al., 1951; White, 1972; Patterson, 1975; Reynolds and Shack, 1976). Coagulants such as various polyelectrolytes, manganese dioxide, alum and lime can also break emulsions and enhance gravity separation.

Of the oxidants mentioned above, chlorine and hypochlorite are very commonly used because of their application to disinfection of drinking water and sewage. The literature indicates that oxidation of phenolics by chlorine occurs most readily in the pH range of 7 to 10 (Armco et al., 1951). When dosage and/or reaction time are insufficient for complete oxidation, partial chlorination using chlorine or hypochlorite has the danger of producing chlorophenols, which tend to increase taste and odor problems (Morris, 1975). There also is a general concern that chlorination of some hydrocarbons may result in a release of potentially harmful compounds in the effluent (Kelley, 1975; Morris, 1975).

Chlorinated hydrocarbon production can be minimized or avoided by use of other oxidants either in combination with or in place of chlorine and hypochlorite. Ozone, chlorine dioxide and potassium permanganate have been found to oxidize aromatic hydrocarbons without the production of undesirable products (Armco et al., 1951; Carus, 1971; White, 1972; Johnson, 1975). Of these, ozone has the disadvantage of requiring on-site generation with expensive capital and operating costs. Oxidation by potassium permanganate will result in the formation of manganese dioxide, a coagulant, and the production of significant quantities of sludge.

Although some investigations have identified trace chlorinated aromatic compounds produced by oxidation of phenolics with chlorine dioxide (Lindgren and Ericsson, 1969), pilot and plant scale operations using chlorine dioxide have shown that partial or complete oxidation of phenolics and COD can be achieved without formation of significant chlorophenols. Control of phenolic tastes and odors has required dosages of 0.3 to 10 pounds of sodium chlorite per million gallons of wastewater (White, 1972). Sodium chlorite is oxidized by Cl_2 to generate ClO_2 in most operations. Experimental oxidation of coke plant wastes showed that use of chlorine dioxide in combination with chlorine gas improved efficiency of using chlorine dioxide alone. Substantial elimination of phenolics appeared to be achieved in a period of 5 minutes or less (Armco et al., 1951).

Literature information and theoretical half-reaction stages for oxidation of organic compounds by chlorine dioxide indicate that a drop in pH can be anticipated as a result of the use of chlorine dioxide. Experimental use of chlorine dioxide to remove phenolics from coke plant waste with phenolic concentrations in the range of 80 to 200 mg/l resulted in a drop of up to 9.8 pH units. It appears that creation of both organic and inorganic acids is likely responsible for this change. Of the inorganic acids that may be produced, some have low dissociation constants, indicating they are strong acids. For example, $HClO_3$ could be produced during oxidation with chlorine dioxide and has a dissociation constant greater than 1, indicating it is a very strong acid (Johnson, 1975). HOCl, which is produced during conventional chlorination, is a weak acid by comparison with a dissociation constant of 2.9×10^{-8}.

To indicate the degree to which chemical oxidants might be effective in removing organics from the effluent from the gradient control system, several preliminary tests were conducted using sodium hypochlorite and potassium permanganate as oxidizing agents. Chlorine dioxide supplies for limited laboratory experiments could not be located.

For the oxidation experiments, ground water from Well 13 was diluted by 50% and by 98% with deionized water in an attempt to produce concentrations likely to be representative of effluent from the gradient control wells. Diluted samples were then oxidized with sodium hypochlorite (NaOCl) and potassium permanganate ($KMnO_4$) at concentrations based on literature information (Reynolds and Shack, 1976; Carus, 1971). A one-hour contact time was used to guarantee relatively complete oxidation reactions. After oxidation, NaOCl-oxidized samples were analyzed for phenolics, COD and pH. In addition, the most heavily oxidized sample from each dilution was analyzed for suspended solids and oil and grease, and each sample in the 50% dilution series was analyzed for biochemical oxygen demand. One sample was oxidized with $KMnO_4$ for comparison with NaOCl. This sample was analyzed for phenolics.

The results of these experiments are summarized in Table F-1 and show that both sodium hypochlorite and potassium permanganate were capable of oxidizing the organics from the middle drift aquifer. Phenolic removals were 12% or less where NaOCl dosages were not significantly greater than the theoretical requirement for complete decomposition. This is in agreement with the findings of others (Reynolds and Shack, 1976). Phenolic removals improved significantly with increased NaOCl dosage. On the other hand, COD removal appears to improve slightly with oxidant concentrations and with dilution. Since COD analyses do not measure aromatic hydrocarbons, this may reflect COD generation by the cleavage of aromatic rings partially compensating for COD destruction by chlorination. Oxidation efficiency appears to have been significantly higher with potassium permanganate than with sodium hypochlorite. This may have occurred because of a more specific affinity of $KMnO_4$ for phenolics, because of reaction pH, or for some other reason.

An undesirable byproduct of oxidation is the formation of suspended solids, especially with $KMnO_4$. After oxidation, suspended solids concentrations were measured in the samples oxidized with the highest hypochlorite dosages and were found to have increased by a factor of about two or more. Solids production in the sample oxidized with $KMnO_4$ was much more dramatic, with formation of a heavy sludge which occupied about 10% of the volume after a settling period of about 1 hour. Visual inspection of the remaining oxidized samples the next day revealed that quiescent settling had removed substantially all turbidity from the samples.

In conclusion, experiment data indicate that the organics under study are amenable to treatment by chemical oxidation in a manner that is consistent with experience reported by others. High dosage requirements and sludge generation must be assumed if this is the only method of treatment employed. These processes appear to be helpful in breaking emulsions and enhancing gravity clarification.

Biological Treatment

Biological oxidation of phenolics and other organic wastes have received a tremendous amount of attention over the years. Trickling filters, activated sludge, oxidation ponds and other applications have been used on experimental and plant scale to remove COD, phenolics and aromatic hydrocarbons. In most cases, removal of emulsified oils to about 100 mg/1 is necessary prior to biological treatment (Reynolds and Shack, 1976). This could complicate the use of biological treatment for direct oxidation of organics in the undiluted effluent from the gradient control wells. Examination of microbial degradation of these materials has led to isolation of various common microbes that are capable of oxidizing specific organics (McKenna and Heath, 1976; Cobb, 1973) and to the suggestion that toxic metabolic byproducts may be responsible for failure of unacclimated microbes to degrade some organics (Baird et al., 1974). Patterson (1975) and Reynolds and Shack (1976) present brief reviews of applications of biological treatment to oxidation of phenolics and creosote wastes. Removals of phenolics and COD ranging from poor to substantially complete removal are reported.

Several aspects of biological treatment must be considered in the treatment of organic wastes. First, all biological systems are susceptible to upsets due to variations in influent quality and to seasonal factors. Changes in waste strength, microbial nutrient balance, toxic chemical concentrations, hydraulic loadings, sunlight and temperature may affect the efficiency of the process. The production of biological solids can result in the need for sludge handling, although extended aeration can be used to reduce the volume of sludge. To maintain aerobic conditions, oxygen supply systems are often needed. Biological treatment will need regular attention by trained personnel to control and maintain the treatment efficiency.

To examine the effluent from the gradient control wells for biological treatability, several tests were made using various ground water samples. These tests are summarized in Table F-2. They were conducted to indicate the biochemical oxygen demand of the raw water and to indicate whether or not prior chemical oxidation would seriously affect biodegradation.

Variations in 5-day BOD of samples taken June 2, 1977 may reflect variations in organic species found among the different sources. Failure of BOD tests to yield results for most samples probably reflects a combination of dilution in the BOD bottles and toxic effects due to the complex nature of organics present in the ground water. As the data indicates, the 5-day BOD's of samples taken June 2 from Well 13 and Well 17 were about 2,000 mg/l and 30 mg/l, respectively.

Other BOD experiments were run with samples collected June 22, 1977 after 50% dilution with deionized water and oxidation with NaOCl. The 5-day BOD's of these samples were in the range of 2,000 to 3,000 mg/l, indicating that the 5-day BOD of the raw ground water obtained June 22 may have been in the range of 4,000 to 6,000 mg/l. This conclusion is supported by the fact that raw water COD was significantly higher on June 22 than on June 2. Reduction of toxic compounds due to chemical oxidation and variations in microbial seed or nutrient availability may also have been responsible for this change in BOD. While a sample of domestic sewage was used as the seed on June 2, water taken from the storm water pond south of Lake Street in the study area was used as the seed source in the second set of experiments, on the theory that these microbes might be better acclimated to metabolize phenolics and other aromatic hydrocarbons.

Data from the BOD tests of June 22 provide sufficient information to estimate BOD kinetic parameters for the oxidized ground water. Once initiated, microbial activity was vigorous and results indicated first order BOD reaction rate constants, K (base e), in the range of 0.6 to 1.2. The ultimate carbonaceous BOD, L, was estimated to range from 2,500 mg/l to 3,200 mg/l. Both K and L may increase with better acclimated microbes or other factors. Values of both K and L were found to decrease somewhat with heavy applications of NaOCl during pretreatment, probably as a result of the chemical oxidation. Compared with "strong wastewater"--where K and L values of about 0.4 and 250 might be expected (Fair et al., 1968)--this indicates an extremely strong wastewater and very rapid microbial response. Based on this information, substantially complete removal of metabolizable BOD should take place within about 4 to 8 days.

These BOD analyses are consistent with the complexity of the organic chemicals present in the ground water, the variations in water quality parameters throughout the study area, the high concentrations of oxygen-demanding substances in various ground water samples and the difficulties inherent in analyses of biodegradation where unusual compounds and potential toxins are present. Results do indicate that these organics should be biodegradable, especially when acclimated microbes are available, and that pre-treatment by oxidation with hypochlorite does not seriously inhibit biodegradation. Additional testing would be necessary to define the biodegradability of these organics more accurately.

TABLE F-1

EFFECTS OF CHEMICAL OXIDANTS ON QUALITY OF GROUND WATER[a]

Oxidant Dosage (mg/mg phenols)	Dilution Ratio[b]	Approximate Initial Phenols (mg/l)[c]	Final Phenols (mg/l)	Percent Removal	Approximate Initial COD (mg/l)[c]	Final COD (mg/l)	Percent Removal	Approximate Initial Suspended Solids (mg/l)[c]	Final Suspended Solids (mg/l)	Final pH[d]
2.9 NaOCl	1:2	25	22	12	20,100	11,300	44	--	--	8.0
	1:50	1.0	2.5[e]	None	800	384	52	--	--	7.1
11.4 NaOCl	1:2	25	7.5	70	20,100	11,000	45	--	--	8.5
	1:50	1.0	0.38	62	800	376	53	--	--	7.9
52.2 NaOCl	1:2	25	2.2	91	20,100	10,500	48	240	463	9.1
	1:50	1.0	0.088	91	800	384	52	10	61	8.5
14 $KMnO_4$	1:2	25	3.0	88	--	--	--	--	--	--

[a]All samples reacted for 1 hour prior to chemical analyses.

[b]Raw water was diluted with deionized water. Raw water had 50 mg/l phenols, 40,200 mg/l COD, 486 mg/l suspended solids, and pH 7.5. Source of raw water was sample taken from Well 13.

[c]Initial concentrations estimated based on dilution factors.

[d]pH was primarily influenced by the pH of the concentrated oxidant (12.6). Little or no change was observed during reaction.

[e]Inconsistent data. Probably reflects uneven distribution of organics in raw water prior to dilution or an error in analysis. Raw water was shaken thoroughly before samples were withdrawn.

TABLE F-2

SUMMARY OF BIOCHEMICAL OXYGEN DEMAND DATA

A. 5-Day BOD of Samples Taken June 2, 1977

	Volume of Sample in 303 ml BOD Bottle (ml)*					
Source	0.03	0.5	1.0	3.0	10.0	30.0
Well 5	ND	ND	ND	ND	ND	ND
Well 6	ND	ND	ND	ND	ND	ND
Well 9	ND	ND	ND	ND	ND	ND
Well 13	ND	2,200	1,700	ND	ND	ND
Well 17	ND	ND	ND	ND	ND	30

B. 5-Day BOD of Well 13 Samples Taken June 22, 1977 After 50% Dilution With Deionized Water and Chemical Oxidation With NaOCl

NaOCl Dosage	Volume of Sample in 303 ml BOD Bottle (ml)*			
(mg/l)	3.0	1.0	0.5	0.1
72	>460	>1,400	>1,500	3,000
280	>460	>1,400	>1,400	1,800
1,300	>460	>1,400	>1,600	2,400

*Balance of bottle was filled with deionized water.

ND means "non detected."

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